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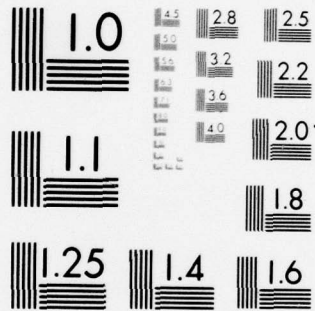
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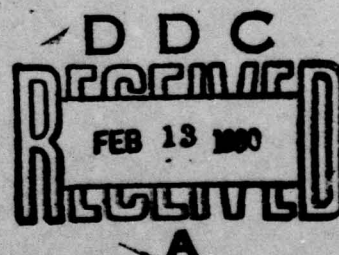
FEATURES STUDY - A STUDY OF RF EXTERNAL TRANSMISSIONS

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) Cepstrum and Fast Fourier Transform techniques are developed which provide a theoretical basis for determining the configuration of aircraft and space vehicles. Some of the limiting assumptions of the analysis, and possible problem areas are discussed. The antenna radiation pattern of an "omnidirectional" antenna is largely determined by the shape, composition, location and size of the features of the vehicle to which the antenna is attached. The objective of this effort was to develop a method for determining the features and/or (Cont'd)			

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configuration of an aircraft or space vehicle from signals transmitted by those vehicles. A signal processing technique called Cepstral Processing offered the best chance to do this. Cepstral Processing is based on the fact that an RF signal sensed in the far field of the transmitting antenna will be a complex composite of the direct antenna signal path, and multipath reflections from vehicle wing surfaces, landing gear struts, fuel pods, etc.

This report documents two possible approaches for extracting required feature information from omnidirectional signals. The first approach is Time Signal Processing. If the transmitter is producing a pulsed waveform (such as a data link signal) each pulse should contain the direct signal plus the attenuated delayed signals resulting from on-board reflectors (surfaces, wings, etc). Cepstral Processing can be applied to the RF, IF, or base band waveform with the result being a plot of the time delay and amplitude of each reflection. While this does not uniquely locate each reflector it does identify that the object location is on an ellipse with the transmitter antenna and the receiving antenna being at the foci. Taking several aspect angles, these ellipses will cross at a point and therefore fix the object position.

The second approach Antenna Radiation Pattern Processing. Here 90° of aspect angle change is non-uniformly sampled in a manner consistent with the Cepstrum equations and again the result is a plot of time delay and amplitude of reflections.

While both approaches give the same type of output, they are complementary not redundant. For a specific situation one may be desired over the other. Both approaches appear feasible at this time, but future effort should investigate the effects of noise, digitization sampling rates, non-linearity of receivers, non-omnidirectional reflections, and object location ambiguity.

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PREFACE

This effort was conducted by Syracuse University under the sponsorship of the Rome Air Development Center Post-Doctoral Program for Rome Air Development Center. Capt. Jeffrey Knieriemen, RADC/IRAE, was the task project engineer and provided overall technical direction and guidance.

The RADC Post-Doctoral Program is a cooperative venture between RADC and some sixty-five universities eligible to participate in the program. Syracuse University (Department of Electrical Engineering), Purdue University (School of Electrical Engineering), Georgia Institute of Technology (School of Electrical Engineering), and State University of New York at Binghamton (Department of Electrical Engineering) act as prime contractor schools with other schools participating via sub-contracts with prime schools. The U.S. Air Force Academy (Department of Electrical Engineering), Air Force Institute of Technology (Department of Electrical Engineering), and the Naval Post Graduate School (Department of Electrical Engineering) also participate in the program.

The Post-Doctoral Program provides an opportunity for faculty at participating universities to spend up to one year full time on exploration, development and problem-solving efforts with the post-doctorals splitting their time between the customer location and their educational institutions. The program is totally customer-funded with current projects being undertaken for Rome Air Development Center (RADC), Space and Missile Systems Organization (SAMSO), Aeronautical System Division (ASD),

Electronics Systems Division (ESD), Air Force Avionics Laboratory (AFAL), Foreign Technology Division (FTD), Air Force Weapons Laboratory (AFWL), Armament Development and Test Center (ADTC), Air Force Communications Service (AFCS), Aerospace Defense Command (ADC), HQ USAF, Defense Communications Agency (DCA), Navy, Army, Aerospace Medical Division (AMD), and Federal Aviation Administration (FAA).

Further information about the RADC Post-Doctoral Program can be obtained from Mr. Jacob Scherer, RADC/RBC, Griffiss AFB, NY, 13441, telephone Autovon 587-2543, Commercial (315) 330-2543.

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EVALUATION

The Features Study Project was fully funded by the Rome Air Development Center Laboratory Director's Fund. Syracuse University has developed two unique approaches for deriving the features, characteristics, and configuration of airborne vehicles. These digital signal processing techniques utilize RF Transmissions from omnidirectional antennas on-board the target vehicle. The Transmissions are received and recorded by remotely located receiving systems. There are many questions still to be resolved, but this effort has provided basic research into an area of very high potential pay-off.

Jeffrey N. Knieriemen

JEFFREY N. KNIERIEMEN, CAPT, USAF
Project Engineer

1. INTRODUCTION

1.1 Objective

This study was motivated by an interest in determining features and characteristics of the configurations of aircraft and space vehicles by monitoring their RF external transmissions. The theoretical foundations are presented in this report, along with simulation results, from which techniques can be developed to implement this method of detection. Additional work is needed to determine whether or not the techniques are practically feasible.

1.2 Background

This was a theoretical study of limited time duration. A survey of the unclassified literature did not reveal any publications relating directly to this subject. Consideration of many of the existing detection techniques, such as those used in radar systems, did not suggest any methods of solution to this proposed problem. Finally, it was decided to concentrate this study on the application of Cepstrum* techniques to this problem.

2. GENERAL APPROACH - CEPSTRUM ANALYSIS

In the analysis that follows, it is assumed that the particular type vehicle which is being monitored has been identified and the objective is that of determining its configuration. In other words, can it be determined

* B.P. Bogert, M.J.R. Healy, and J.W. Tukey, "The Quefrency Analysis of Time Series for Echoes," Pro. Symp. Time Series Analysis, M. Rosenblatt, ed., John Wiley and Sons, N.Y., 1963, pp. 209-243.

if the known type vehicle is armed, are its wheels down, are its wing tanks in place, etc. The general approach to developing such a method of detection is as follows. It is assumed that the RF transmissions of any vehicle of interest has been monitored and recorded in the past when the vehicle is in what may be called a 'normal' or 'neutral' configuration. In the analysis below, this known signal is represented by $x(t)$. Any change in this normal configuration, such as the addition of armaments or wing tanks, will be equivalent to introducing obstacles or scatterers which will affect the patterns of the vehicle's transmitting antennas. In fact, these obstacles are interpreted as point sources of reflections which distort the original signals by causing multipath transmissions. Cepstrum analysis of this multipath signal provides an estimate of the locations of the reflections and, hence, an estimate of the change in the vehicle features.

For example, suppose that an aircraft has an omnidirectional antenna mounted under the fuselage as shown in Figure 1. Furthermore, assume that the far-field signal, $x(t)$, received from this antenna is known. To simplify the illustration assume that the aircraft is moving on a radial straight line toward the receiving site.

Now suppose that armament is placed under the wing as indicated in Figure 2. Under this condition, the received signal is:

$$y(t) = x(t) + \alpha x(t - \tau). \quad (1)$$

The distance d in Fig 2 is related to by:

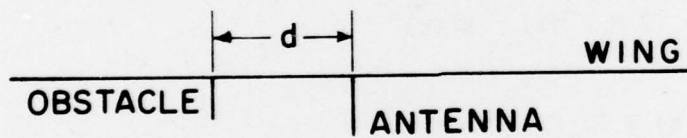
$$d = c\tau, \text{ where } c \text{ is free-space velocity of propagation of the signal.} \quad (2)$$

For a given vehicle, if d is determined, its configuration is known; or,



NORMAL CONFIGURATION OF AIRCRAFT

FIGURE 1



MODIFIED CONFIGURATION OF AIRCRAFT

FIGURE 2

in general, if locations of several sources of reflections are determined, information about the configuration of the vehicle is obtained.

A cepstrum analysis of (1) will now be developed to illustrate how τ and α can be determined.

Take the Fourier transform of (1):

$$Y(\omega) = X(\omega)[1 + \alpha e^{-j\omega\tau}] \quad (3)$$

After this, take the logarithm of both sides:

$$\ln(Y(\omega)) = \ln(X(\omega)) + \ln[1 + \alpha e^{-j\omega\tau}] \quad (4)$$

Assume $|\alpha| \ll 1$. Note: This assumption is not necessary, but it simplifies the analysis.* Then:

$$\ln(Y(\omega)) = \ln(X(\omega)) + \alpha e^{-j\omega\tau} \quad (5)$$

Taking the inverse Fourier transform:

$$\begin{aligned} F^{-1}(\ln Y(\omega)) &= y'(t) = F^{-1}(\ln X(\omega)) + \alpha \delta(t - \tau) \\ &= x'(t) + \alpha \delta(t - \tau) \end{aligned} \quad (6)$$

$$\alpha \delta(t - \tau) = y'(t) - x'(t) \quad (7)$$

where

$$\begin{aligned} \delta(t - \tau) &= 1, & t &= \tau \\ &= 0 & \text{elsewhere.} \end{aligned}$$

Equation (7) is our desired result. Recall that $x(t)$ and, consequently, $x'(t)$ are known. Also, $y(t)$ is the received signal; therefore, $y'(t)$ is known. Therefore, (7) yields an impulse of strength α located

* $\ln(1 + w) = w - \frac{w^2}{2} + \frac{w^3}{3} - \dots = \sum_{n=1}^{\infty} (-1)^{(n+1)} \frac{w^n}{n}; \quad w^2 < 1$

at $t = T$. But $d = cT$ and, therefore, d has been determined. This indicates that an object has been added to the vehicle at a distance, d , from the antenna as indicated in Figure 2. Note: If $|\alpha| \ll 1$ does not hold, equation (7) will include additional terms of the form $(-1)^{(n+1)} \frac{\alpha^n}{n}$. $\delta(t - nT)$ which can be identified and disregarded.

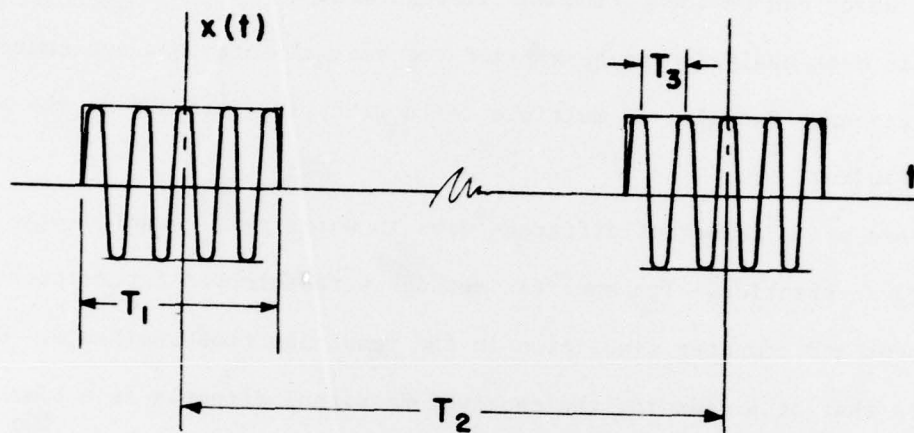
This same analysis can be applied to cases of more than one source of reflections. Examples of multiple reflections are included in the simulation results.

There are a number of different ways in which this technique may be processed in practice. Two specific methods were selected for further development and computer simulation in the remaining time available. One method is that of processing the received RF signal directly as a time function. Because this implementation follows naturally from the cepstrum analysis presented above, it is developed first in this report. The other method monitors and processes the radiation pattern of the RF transmissions. It requires additional innovation and is presented second.

3. TIME SIGNAL PROCESSING

3.1 Analysis

A signal typical of what many aircraft may transmit is shown in Figure 3. It may be processed at the receiver as an RF, IF, or baseband signal. If the receiver does not distort the original multipath relations, it is convenient to process the baseband or envelope signal. As shown in what follows, processing the signal after it has passed through any linear filter, yields the same result.



TYPICAL RF TRANSMISSION

$$(T_1 = 1(10)^{-6} \text{ s}; T_2 = 40(10)^{-6} \text{ s}; f_c = \frac{1}{T_3} = 300(10)^6 \text{ Hz})$$

FIGURE 3

In practice, of course, this analysis would be accomplished on a digital computer using the discrete Fourier transform (DFT) or Fast Fourier Transform (FFT). Consequently, in the example below the signal is given as discrete data and numerical or discrete techniques are used.

The received signal is represented as:

$$y(n) = x(n) + \sum_{i=1}^P \alpha_i x(n - n_i). \quad (8)$$

In (8), $x(n)$ is the received signal when the vehicle is in its 'normal' configuration and $\sum_{i=1}^P \alpha_i x(n - n_i)$ represents the contributions of p obstacles. The variable, time, has been suppressed and the interval $(n(K+1) - n(K))$ corresponds to the unit sampling time, T_s .

If $y(n)$ is passed through a linear filter whose impulse response is $h(n)$,

$$s(n) = y(n) * h(n) \quad (9)$$

where $*$ indicates convolution. Note: Multiplication is represented by the symbol $*$ in the computer printouts.

Taking the Fast Fourier Transform (FFT) of (9) yields:

$$S(K) = Y(K)H(K) = X(K) \left(1 + \sum_{i=1}^P \alpha_i e^{-j(2\pi/N)Kn_i} \right) H(K) \quad (10)$$

where

$$Y(K) = \sum_{n=0}^{(N-1)} [x(n) + \sum_{i=1}^P \alpha_i x(n - n_i)] e^{-j(2\pi/N)Kn} ; \quad K = 0, 1, 2 \dots (N-1) \quad (11)$$

$$H(K) = \sum_{n=0}^{(N-1)} h(n) e^{-j(2\pi/N)Kn} ; K = 0, 1, 2 \dots (N-1) \quad (12)$$

Next:

$$\ln|S(K)|^2 = \ln|X(K)H(K)|^2 + \ln|1 + \sum_{i=1}^P \alpha_i e^{-j(2\pi/N)Kn_i}|^2 \quad (13)$$

Here the $\ln|S(K)|^2$ is used instead of $\ln[S(K)]$ as indicated in Section 2. The logarithm of a complex number is multivalued. Usually, in computations only the principal value is used. When dealing with functions that vary over more than one wavelength, this practice introduces discontinuities and errors in the results. Using the magnitude or absolute value of $S(K)$ eliminates this problem. However, in the result this introduces an impulse at $(N - n_i)$ as well as n_i when a signal $\alpha_i x(n - n_i)$ is present. This additional impulse can be recognized and disregarded as shown in the simulation below.

$$\text{If } |\alpha_i| \ll 1, \text{ i.e., } \alpha_m \alpha_l \approx 0, \quad (14)$$

$$\begin{aligned} \ln|S(K)|^2 &\approx \ln|X(K)H(K)|^2 + \sum_{i=1}^P 2\alpha_i \cos\left(\frac{2\pi}{N} n_i K\right) \\ \sum_{i=1}^P 2\alpha_i \cos\left(\frac{2\pi}{N} n_i K\right) &\approx \ln|S(K)|^2 - \ln|X(K)H(K)|^2 \end{aligned} \quad (15)$$

Applying the inverse FFT (FFT^{-1}):

$$\begin{aligned} \sum_{i=1}^P \alpha_i [\delta(n - n_i) + \delta(n + n_i)] &= \text{FFT}^{-1} \ln|S(K)|^2 - \\ &\quad \text{FFT}^{-1} \ln|X(K)H(K)|^2. \end{aligned} \quad (16)$$

Again, (16) is our desired result. Recall that $X(K)$ is known because $x(n)$ is known and $S(K)$ is determined from $y(n)$ which is the received signal. Note in (16) that there are two impulses for each reflection. Because of the periodicity of the FFT, $(n + n_i) = (N - n_i)$.

Also, if the condition $|\alpha_1| \ll 1$ does not apply, additional impulses are present. This is discussed below. Also note that any processing of the received signal that may be represented by a linear transfer function such as $H(K)$ appearing with the above equations will not affect the results.

3.2 Simulation

This technique was simulated on a digital computer. The program, SILVERMAN/DRSIL, which was used is included in the appendix. The results are as predicted by the theory in these abstract, noiseless examples. Four cases are illustrated in Figures 5 through 25.

Case I: One Reflection

$$\begin{aligned} x(n) &= 1, & 0 \leq n \leq 7 & \quad (\text{Fig. 5}) \\ &= 0, & 8 \leq n \leq 15 \end{aligned}$$

$$\begin{aligned} h(n) &= e^{-0.25n} \\ \alpha &= 0.2 \end{aligned} \quad (\text{Fig. 7})$$

$$n_1 = 3 \quad (\text{delay})$$

Figure 10 is a plot of the cepstrum: $\alpha_1 [\delta(n - n_1) + \delta(n + n_1)] = 0.2 [\delta(n - 3) - \delta(n + 3)]$. Note the amplitude of $\alpha = 0.2$ at $n = 3$ and $n = (N - 3) = 13$. Also note the amplitude $= (-0.1)\alpha = -0.02$ at $n = 6$ and $n = (N - 6) = 10$. These addition impulses occur because of the expression for the logarithm:

$$\ln(1 + w) = w - \frac{w^2}{2} + \frac{w^3}{3} - \frac{w^4}{4} + \dots$$

In the analysis in Section 2 it is assumed that $\ln(1 + w) \approx w$. In this particular case: $w = 2\alpha \cos(\frac{2\pi}{N} n_1 K) = 0.4 \cos \frac{\pi}{8} (3K)$, and

$$\begin{aligned}
-\frac{w^2}{2} &= \frac{(0.4)^2}{2} \cos\left(\frac{\pi}{8} 3K\right)^2 = (0.04)(1 - \cos \frac{\pi}{8} 6K) \\
&= -0.02[1 - e^{j(\pi/8)6K} - e^{-j(\pi/8)6K}]
\end{aligned}$$

This term accounts for the cepstrum responses at $n = 6$ and $n = (N-6) = 10$. Because only the magnitudes of the data are plotted, the minus sign is not apparent at $n = 6$ and $n = 10$, but it did appear in the numerical calculations.

Case 2. Two Reflections

$$\begin{aligned}
x(n) &= 1, & 0 \leq n \leq 7 & \quad (\text{Fig. 11}) \\
&= 0, & 8 \leq n \leq 15
\end{aligned}$$

$$h(n) = e^{-0.25n} \quad (\text{Fig. 7})$$

$$\begin{aligned}
\alpha_1 &= 0.2 & ; \alpha_2 &= 0.1 \\
n_1 &= 3 & ; n_2 &= 4
\end{aligned}$$

Figure 15 is a plot of the cepstrum:

$$\begin{aligned}
&\alpha_1[\delta(n - n_1) + \delta(n + n_2)] + \alpha_2[\delta(n - n_2) + \delta(n + n_2)] \\
&= 0.2[\delta(n - 3) + \delta(n + 3)] + 0.1[\delta(n - 4) + \delta(n + 4)].
\end{aligned}$$

The response is as expected. Note that in addition to the added responses at values of n equal to $2n_1 = 6$; $2n_2 = 8$; $N - 2n_1 = 10$; $N - 2n_2 = 8$, there is also a response at $(n_1 + n_2) = 7$. Again, this does not appear in our original analysis because of approximations. However, note that these additional terms are at least an order of magnitude less than the principal responses and they can be predicted.

Case 3: Two Reflections, Trapezoidal Shape Input Signal:

$$x(n) = \{0.3, 0.7, 1, 1, 1, 0.6, 0.4, 0.2, 0, 0, \dots, 0\} \quad n = 0, 1, 2, \dots, 15.$$

(Fig. 16)

$$h(n) = e^{-0.25n}$$

(Fig. 7)

$$\alpha_1 = 0.2 \quad ; \quad \alpha_2 = 0.1$$

$$n_1 = 3 \quad ; \quad n_2 = 4$$

This example has the same parameters as Case 2, but the function $x(n)$ is different than Case 2. The plots of $x(n)$, $y(n)$, $x(n)*h(n)$, $y(n)*h(n)$, the cepstrum are shown in Figures 16-20. The results are the same as Case 2,

Case 4: One Reflection, Complex Reflection Coefficient

This example has the same parameters as Case 1 except for the reflection coefficient, α . For case 4,

$$\alpha = 0.2 + j0.2.$$

The plots of $x(n)$, $y(n)$, $x(n)*h(n)$, $y(n)*h(n)$, and the cepstrum are shown in Figures 21-25. The results are essentially the same as those of Case 1.

3.3 Summary

Cepstrum processing a signal as a time function has appeal in this detection problem because it requires the briefest time of observation. Although this technique worked well in the ideal computer simulation, there are several factors which may limit its usefulness in practice. Among these factors are:

1. The effect of vehicle orientation on accuracy of results.
2. The receiver transfer function. A careful study should be made

to insure that the receiver does not distort the original multipath relations.

3. Noise. The multipath transmission resulting from the obstacles will contribute low level signal particularly at the trailing edge of the main signal. These must not be masked by the noise.

4. Resolution and sampling rate. The sampling rate determines the minimum distance that two contiguous obstacles can be separated and still be resolved as two (not a single) obstacles.

Recall that the received signal when one reflection is present was represented as:

$$y(t) = x(t) + \alpha x(t - \tau) \quad (1)$$

and

$$d = c\tau. \quad (2)$$

The distance between the transmitting antenna and the source of the reflection is d and c is the free-space velocity of light and equals $300(10)^6$ meters/second.

If $y(t)$ is sampled uniformly every T_s seconds,

$$y(mT_s) = x(mT_s) + \alpha x(mT_s - \tau) \quad (17)$$

or

$$y(n) = x(n) + \alpha x(n - \tau) \quad (18)$$

$$\text{where } n = mT_s. \quad (19)$$

$$\text{Therefore: } n(K+1) - n(K) = (m+1)T_s - mT_s = T_s. \quad (20)$$

Consequently, the shortest distance that can be resolved is:

$$d_{\min} = cT_s = 300(10)^6 T_s \text{ meters.} \quad (21)$$

In practice, various locations of obstacles probably will not correspond exactly to a sampling time n_i . Such an obstacle gives a cepstrum response corresponding to sampling times on either side of the time corresponding to its exact location. This will be demonstrated and discussed in the next section. If there are two or more obstacles in a distance corresponding to one sampling interval, T_s , they cannot be resolved. Equation 21 indicates that if T_s equals 10/3 nanoseconds, the resolution distance is 1 meter; however, if T_s equals 1 microsecond, the resolution distance is 300 meters.

5. There are other considerations common to all the methods considered in this detection problem which are discussed in the conclusions.

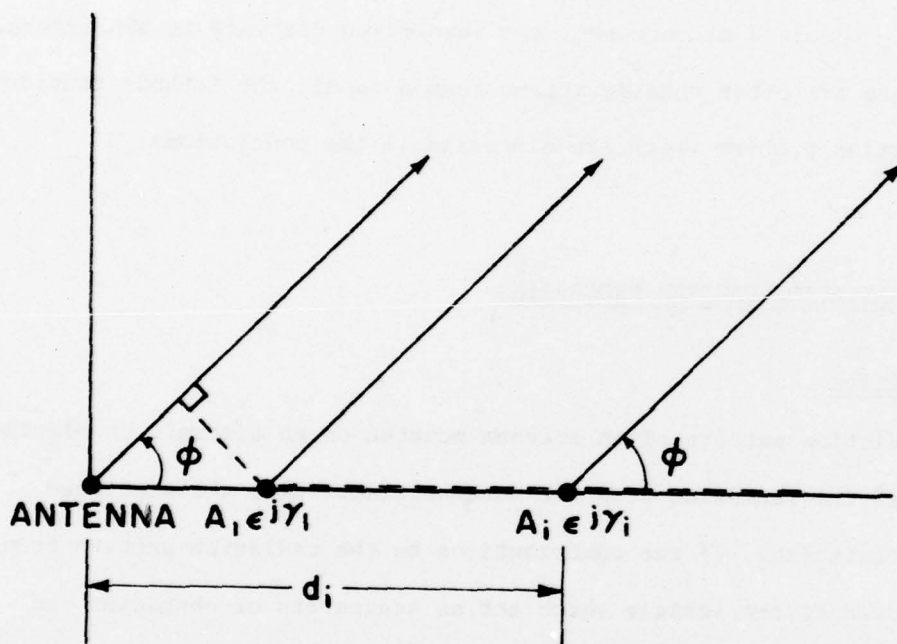
4. ANTENNA RADIATION PATTERN PROCESSING

4.1 Introduction

The radiation pattern of an antenna mounted on an aircraft or missile is composed of the radiation from the antenna itself plus the scattered fields from obstacles. If the contributions to the radiation pattern from components added to the vehicle which act as scatterers or obstacles can be identified, the information can be used to estimate the vehicle configuration. A technique which accomplishes this is described below.

Figure 4 represents an omnidirectional antenna at the origin plus N obstacles contributing to a far-field pattern, $E(\phi)$:

$$E(\phi) = 1 + \sum_{i=1}^N A_i \epsilon^{j\gamma_i} \epsilon^{j(2\pi/\lambda)d_i \cos\phi} \quad (22)$$



REFLECTIONS FROM OBSTACLES WHICH CONTRIBUTE
TO ANTENNA FAR-FIELD

FIGURE 4

where:

A_i = amplitude of scattering signals,

γ_i = phase of scattering signals,

λ = wavelength of transmitted signal.

The field strength of the antenna at the origin has been assumed to equal 1.

Note that the scattering from the obstacles has been assumed omnidirectional also. This may not be true. However, as will be seen in Section 4, the sampling of the antenna pattern is done over a limited range of angle (never greater than $\pi/2$). Consequently, the hypothesis of omnidirectional scattering is reasonable.

To illustrate the method, assume that there is only one obstacle or scatterer a distance d from the antenna and that d/λ is an integer. These restrictions will be removed later. Under these conditions, the far field may be represented as:

$$E(\phi) = 1 + A\epsilon^{j\gamma_\epsilon + j((2\pi/\lambda)d\cos\phi)}. \quad (23)$$

Our problem is to determine d . We proceed as follows. The pattern is sampled at K values of ϕ . The method of determining ϕ_K , the K values of ϕ , results from the analysis below.

$$E(K) = E(\phi_K) = 1 + A\epsilon^{j\gamma_\epsilon + j(2\pi d/\lambda)\cos\phi_K} \quad (24)$$

Now take the discrete Fourier transform (DFT) of (24)

$$e(n) = \sum_{K=0}^{(N-1)} (1 + A\epsilon^{j\gamma_\epsilon + j((2\pi d/\lambda)\cos\phi_K)}) \epsilon^{-j(2\pi/N)nK} \quad (25)$$

$$= N\delta(n) + A\epsilon^{j\gamma_\epsilon} \sum_{K=0}^{(N-1)} e^{-j\frac{2\pi}{N}K(n - (N/K)(d/\lambda)\cos\phi_K)} ; \quad n = 0, 1, 2, \dots, (N-1) \quad (26)$$

If the sampling is done such that $\frac{N}{K} \frac{d}{\gamma} \cos \phi_K = n_0$, where n_0 is an integer constant, $1 \leq n_0 \leq (N-1)$,

$$\begin{aligned} e(n) &= A\epsilon^{j\gamma} \sum_{K=0}^{(N-1)} \epsilon^{-j \frac{2\pi}{N} K(n-n_0)} + N\delta(n) \\ &= NA\epsilon^{j\gamma} \delta(n - n_0) + N\delta(n) \end{aligned} \quad (27)$$

In other words, under these conditions the Fourier transform of the pattern yields an impulse at n_0 .

How can this be used to determine d ? This can be done choosing the ϕ_K 's judiciously.

$$\text{If we sample } \phi \text{ such that } \cos \phi = \left(\frac{K}{N}\right), \quad (28)^*$$

$$\frac{d}{\lambda} = n_0. \quad (29)$$

This represents the essence of the method. To summarize, if the pattern is sampled in the non-uniform manner as described by (28), the DFT of this data includes an impulse at n_0 where $d = \lambda n_0$. Consequently, the position of the added obstacle with respect to the antenna has been estimated.

It has been assumed for simplicity that d/λ is an integer and that only one obstacle is present. These requirements are relaxed in the more general results developed below. Also, the validity of this method is demonstrated by the results of a number of computer simulations.

In the simulation program, the inverse FFT is used instead of the FFT and, therefore, the factor N multiplying (27) does not appear in the simulation results. Also, the magnitude only of the data multiplied by the scale

*This implies that the pattern is sampled over the range: $0 \leq \phi < \frac{\pi}{2}$.

factor 10 is plotted in all graphs.

Also, it should be pointed out that while this method resulted from a study of cepstrum techniques, it does not make use of cepstrum analysis.

It is based on the following observations:

1. In (26), which is DFT of the sampled values of the radiation pattern,

$$\sum_{K=0}^{(N-1)} \epsilon^{-j \frac{2\pi}{N} K(n-n_0)} \equiv 0$$

unless $(n-n_0) = 0$, where $n_0 = \frac{N}{K} \frac{d}{\lambda} \cos \phi_K$.

2. Consequently, if the sampling points, ϕ_K are picked such that $\cos \phi_K = K/N$, (26) will be zero for all n except the impulse at the origin and value at $n = n_0 = d/\lambda$. This is indicated in (27).

4.2 Simulation: $d/\lambda = \text{Integer}$; Single Reflection.

The computer program, NYAKA/CEPMLD, was used to carry out the simulation of this technique. A copy of the computer program is included in the appendix.

Case 1: Single Reflection

Figure 26: $A\epsilon^{j\gamma} = 0.2$

$$d/\lambda = 3$$

Number of Sample Points = 8

Figure 27: $A\epsilon^{j\gamma} = 0.2$

$$d/\lambda = 3$$

Number of Sample Points = 16.

Figure 28: $A\epsilon^{j\gamma} = 0.2$

$$d/\lambda = 3$$

Number of Sample Points = 32

These three cases were run to indicate that the number of sample points does not affect the results.

Case 2. $d_1/\lambda = \text{Integer}$; Multiple Reflections

Where more than one reflection is present and all are integer multiple of λ from the antenna at the origin, the analysis can be extended in an obvious manner. The DFT of (22) is:

$$e(n) = N[\delta(n) + \sum_{i=1}^N A_i \epsilon^{j\gamma_i} \delta(n - n_i)] \quad (30)$$

where $\cos \phi_K = \frac{K}{N}$ and $d_i = n_i \lambda$. This is illustrated in the following figures:

Figure 29: $A\epsilon^{j\lambda} = 0.3$

$$d/\lambda = 7$$

Number of Sample Points = 32

Figure 30: $A_1 \epsilon^{j\gamma_1} = 0.2$; $A_2 \epsilon^{j\gamma_2} = 0.1$

$$d_1/\lambda = 3 \quad ; \quad d_2/\lambda = 6$$

Number of Sample Points = 32.

Figure 31: $A_1 \epsilon^{j\gamma_1} = 0.4$; $A_2 \epsilon^{j\gamma_2} = 0.1$; $A_3 \epsilon^{j\gamma_3} = 0.2$

$$d_1/\lambda = 2 \quad ; \quad d_2/\lambda = 7 \quad ; \quad d_3/\lambda = 13$$

Number of Sample Points = 32.

These results are as predicted by the analysis.

Case 3: $d/\lambda = \text{Noninteger}$; Integer Program

In this series of simulations the same processing (or program) was used as in cases 1 and 2, but d was not equal to integer multiples of λ . Notice that it is still possible to estimate the locations of the sources of reflection. Experience can improve the accuracy of these estimates. Better estimates can be obtained by more sophisticated processing such as described in Cases 4 and 5.

Fig. 32: $A\epsilon^{j\gamma} = 0.2$

$$d/\lambda = 3.2$$

Fig. 33: $A\epsilon^{j\gamma} = 0.2$

$$d/\lambda = 3.5$$

Fig. 34: $A\epsilon^{j\gamma} = 0.2$

$$d/\lambda = 3.8$$

Fig. 35: $A_1\epsilon^{j\gamma_1} = 0.2$; $A_2\epsilon^{j\gamma_2} = 0.2$; $A_3\epsilon^{j\gamma_3} = 0.4$

$$d_1/\lambda = 2.25; \quad d_2/\lambda = 2.75; \quad d_3/\lambda = 5$$

Fig. 36: $A_1\epsilon^{j\gamma_1} = 0.3$; $A_2\epsilon^{j\gamma_2} = 0.1$; $A_3\epsilon^{j\gamma_3} = 0.2$

$$d_1/\lambda = 2.3 \quad ; \quad d_2/\lambda = 2.65 \quad ; \quad d_3/\lambda = 5$$

Observe that in all these cases, the largest response occurs at the value of n that corresponds to the best approximation of d/λ . However, experience and/or further analysis is required to develop rules about whether the spurious responses correspond to weak reflections or may be disregarded. For instance in Figure 33 where $d/\lambda = 3.5$, the response is

symmetrical about that point and, with experience, one would interpret this as a single reflection at $d/\lambda = 3.5$.

Because, in general, d/λ will not equal an integer, methods of detecting any value of d were investigated. Some of these results are described below.

Case 4: $d/\lambda = \text{Noninteger}$; Modified Processing; One Reflection

In the analysis of this method in Section 4.1 in equation 25, we set

$$\frac{N}{K} \frac{d}{\lambda} \cos \phi_K = n_0 \quad (31)$$

and

$$\cos \phi_K = \frac{K}{N} \quad (32)$$

so that

$$\frac{d}{\lambda} = n_0$$

and a response occurred at n_0 .

On the other hand, consider the case where:

$$\frac{d}{\lambda} = (m + \frac{p}{q}) \quad ; \quad p, q, m \text{ are integers} \quad (33)$$

$$\text{Also assume that: } N = Jq \quad ; \quad J \text{ and } q \text{ are integers} \quad (34)$$

Now, for a response at n_0 ,

$$n_0 = \frac{N}{K} \frac{d}{\lambda} \cos \phi = Jq \frac{(qm + p)}{qK} \cos \phi_K \quad (35)$$

$$\text{Let } \cos \phi_K = \frac{r_0^K}{J(qm + p)} \quad ; \quad K = 0, 1, 2 \dots (N-1) \quad (36)$$

and $n_0 = r_0$.

Because $|\cos \phi_K| \leq 1$ and $0 \leq K \leq (N-1)$,

$$r_0 \leq \frac{J(qm + p)}{(N - 1)} \quad (37)$$

Equation (36) gives the rule for determining the sample values of ϕ_K . Under these conditions, a response at $n = r_0$ indicates an obstacle at $d/\lambda = (m + \frac{p}{q})$. This is illustrated in Figures 37 and 38.

Fig. 37: $A\epsilon^{j\gamma} = 0.45$

$$\frac{d}{\lambda} = 3.5 = 3 + \frac{1}{2}$$

$$\cos \phi_K = \frac{1K}{16(7)} = \frac{K}{112} \quad ; \quad K = 0, 1, 2 \dots (N-1)^*$$

A response, $\delta(n - 1) = 0.45$, is observed in Fig. 37.

Fig. 38: $A\epsilon^{j\gamma} = 0.45$

$$\frac{d}{\lambda} = 10.5 = 3(3.5) = 3(3 + \frac{1}{2})$$

$$\cos \phi_K = \frac{K}{112} \quad ; \quad K = 0, 1, 2, \dots (N-1)$$

In this case where $d/\lambda = 3(m + \frac{p}{q})$, the response occurs at $n=3$ as indicated in Fig. 38.

Case 5: $d/\lambda = \text{Noninteger}$; Modified Processing; Multiple Reflections

Routines were developed to detect multiple reflections located at noninteger values of d/λ . One will be illustrated for a particular case of two reflections. Rewrite (24), the equation for the sampled field, as:

$$E(K) = E(\phi_K) = 1 + A_1 \epsilon^{j\gamma_1} \epsilon^{j(\frac{2\pi}{\lambda} d_1 \cos \phi_K)} + A_2 \epsilon^{j\gamma_2} \epsilon^{j(\frac{2\pi}{\lambda} d_2 \cos \phi_K)}$$

* In the processing modified for noninteger values of d/λ , ϕ is sampled over an even smaller range than $\pi/2$.

$$\begin{aligned}
e(n) &= \sum_{K=0}^{(N-1)} [1 + A_1 \epsilon^{j\gamma_1} \epsilon^{j\frac{2\pi}{\lambda} d_1 \cos \phi_K} + A_2 \epsilon^{j\gamma_2} \epsilon^{j\frac{2\pi}{\lambda} d_2 \cos \phi_K}] \epsilon^{-j\frac{2\pi}{N} nK} \\
&= N\delta(n) + \sum_{K=1}^{(N-1)} [A_1 \epsilon^{j\gamma_1} \epsilon^{-j(n - \frac{d_1}{\lambda} \frac{N}{K} \cos \phi_K)} \\
&\quad + A_2 \epsilon^{j\gamma_2} \epsilon^{-j(n - \frac{d_2}{\lambda} \frac{N}{K} \cos \phi_K)}] \epsilon^{-j\frac{2\pi}{N} nK}
\end{aligned}$$

We wish to choose the sample points, ϕ_K , of the antenna pattern such that:

$$n_1 - \frac{d_1}{\lambda} \frac{N}{K} \cos \phi_K = 0 = n_2 - \frac{d_2}{\lambda} \frac{N}{K} \cos \phi_K.$$

Under this condition, a response at n_1 will indicate a source of reflection at d_1 and a response at n_2 will indicate a source of reflection at d_2 .

$$\text{Let: } \frac{d_1}{\lambda} = (m_1 + \frac{p_1}{q_1}) \text{ and } \frac{d_2}{\lambda} = (m_2 + \frac{p_2}{q_2}).$$

$$\text{Then: } \cos \phi_K = n_1 \frac{K}{N} (\frac{q_1}{m_1 q_1 + p_1}) = n_2 \frac{K}{N} (\frac{q_2}{m_2 q_2 + p_2})$$

$$\text{Suppose: } N = 32; \quad \frac{d_1}{\lambda} = 1.25 = \frac{5}{4}; \quad \frac{d_2}{\lambda} = 2.5 = \frac{5}{2}.$$

$$\begin{aligned}
\cos \phi_K &= n_1 K \frac{(4)}{32(5)} = n_2 K \frac{(2)}{32(5)} \\
&= n_1 \frac{K}{40} = \frac{n_2 K}{2(40)}
\end{aligned}$$

Therefore, if we let $n_1 = 1$ and $n_2 = 2$,

$$\cos \phi_K = \frac{K}{40} ; \quad K = 0, 1, 2, 3, \dots (N-1)$$

and the sample points are determined by the formula:

$$\phi_K = \arccos \frac{K}{40} ; K = 0, 1, 2, \dots (N-1).$$

This is illustrated in Fig. 39.

$$A_1 \varepsilon^{j\gamma_1} = 0.3 ; A_2 \varepsilon^{j\gamma_2} = 0.45$$

$$\frac{d_1}{\lambda} = 1.25 ; \frac{d_2}{\lambda} = 2.5$$

$$\cos \phi_K = \frac{K}{40} ; K = 0, 1, 2, 3 \dots (N-1)$$

The results are as predicted by the analysis.

4.3 Summary

The analysis and simulation in Section 4 demonstrate the soundness of technique of detecting multiple reflections of a vehicle by monitoring its RF transmissions. This was accomplished by a special non-uniform sampling of its radiation pattern and applying the FFT. Some of the unsolved problems are:

1. The analysis assumed a linear array of reflectors. This must be generalized to include the case of reflectors at arbitrary positions.
2. The problem of the minimum distance between two obstacles that can be resolved by this method has not been studied. It is clear that $d \geq \lambda$ can be resolved.
3. The effect of noise has not been considered.
4. General problems are included in the conclusions.

5. CONCLUSION

The theoretical soundness of applying cepstrum and associated techniques to the problem of determining a vehicle's configuration by monitoring its RF external transmissions has been demonstrated by the analysis and simulation developed in this report. The results are sufficiently promising to warrant further study to determine if these methods are practically feasible.

A number of assumptions and limitations in this study should be investigated.

1. It was assumed that the obstacles can be represented as point sources of reflections with omnidirectional scattering patterns. This must be checked.
2. Reflections and scattering from the terrain and other sources have been neglected. The validity of this assumption must be investigated.
3. Performance of this technique in a real, noisy environment must be investigated.
4. The ability of this technique to resolve distinct obstacles, in practice, must be verified. This is related to (1) above.
5. Throughout the work in this report we have solved for the distance, d , between an antenna and a scattering obstacle. This does not give a precise location of the obstacle. This result, d , depends on the difference in total time of transmission of the received signal from the antenna and the scattering obstacle. Therefore, the point determined by d can lie anywhere on an ellipse whose foci are the transmitting antenna

and the receiver. Strategies, such as performing more than one measurement, should be studied which will give a better estimate of the exact location of the source of reflection or scattering.

6. In addition, there should be further study of problems peculiar to the specific method of signal processing used as discussed in Section 3 and Section 4. This will help determine which specific method is best.

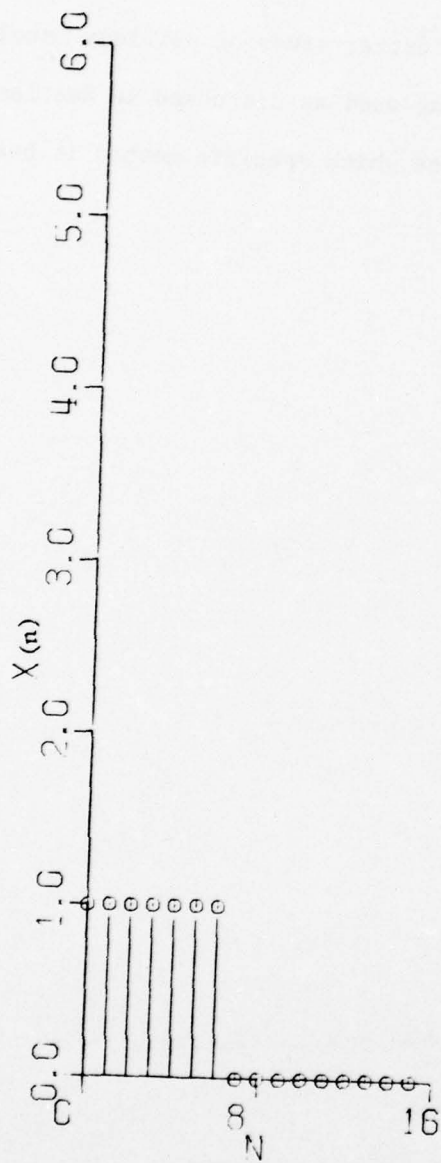


Fig. 5. $x(n)$

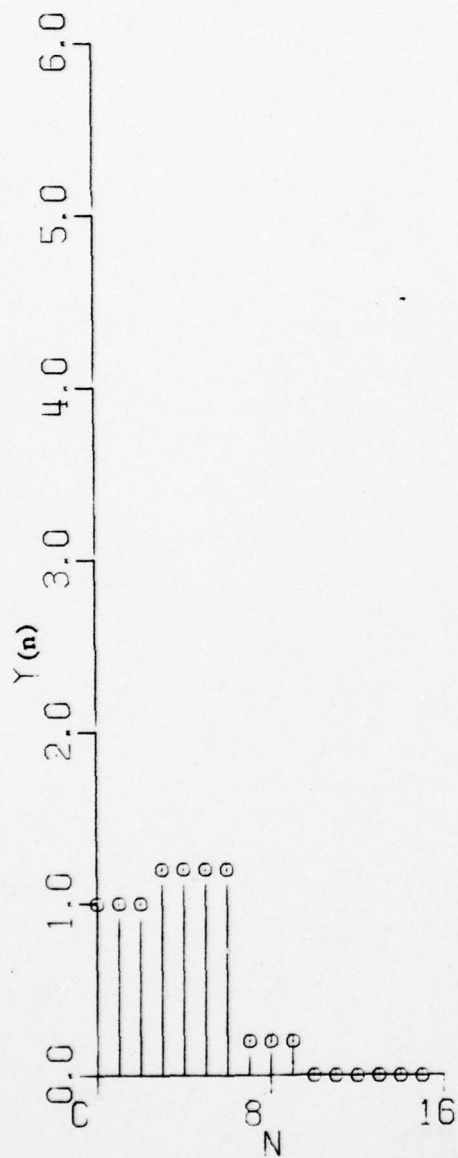


Fig. 6. $y(n) = x(n) + \alpha x(n-n_0) = x(n) + 0.2x(n-3)$

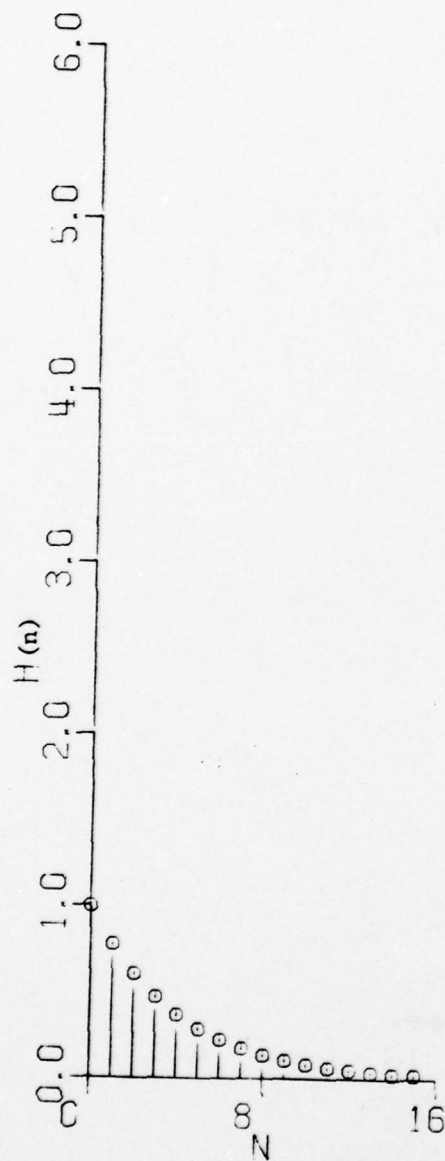


Fig. 7. $h(n) = E^{-0.25n}$

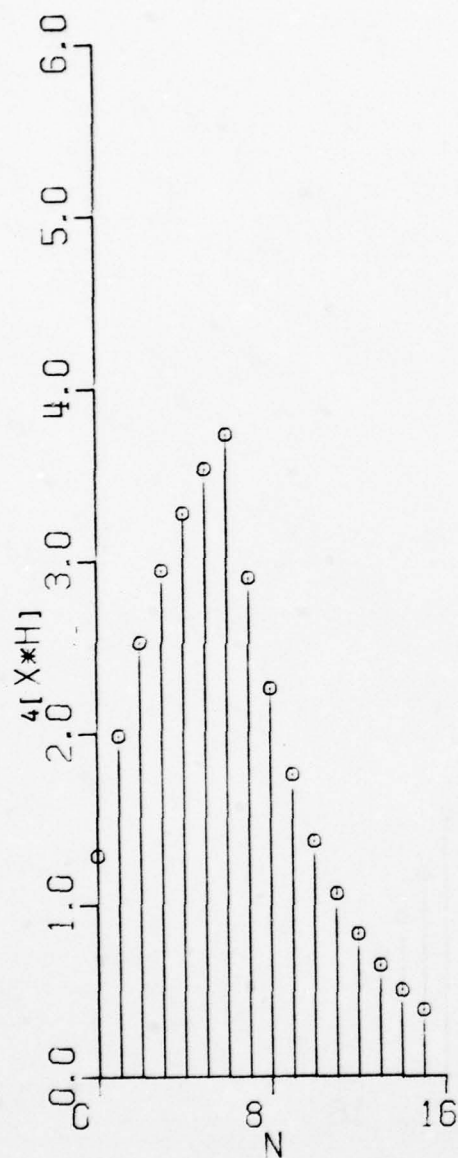


Fig. 8. $4[x(n)*h(n)] = 4R(n)$

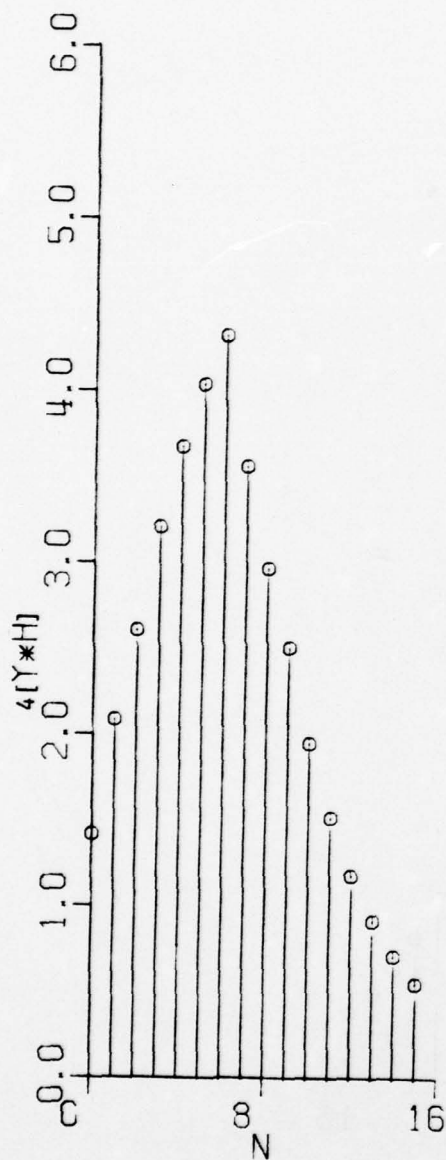


Fig. 9. $4[y(n)*h(n)] = 4s(n)$

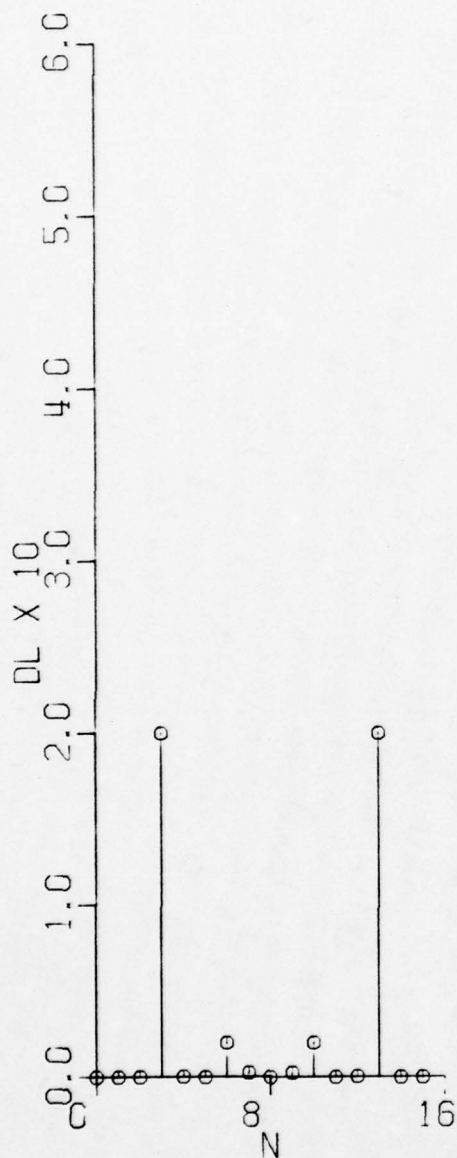


Fig. 10. Real Cepstrum of $s(n) = h(n)[x(n) + 0.2x(n-3)]$
 (see $x(n)$ in Fig. 5; $h(n)$ in Fig. 7)

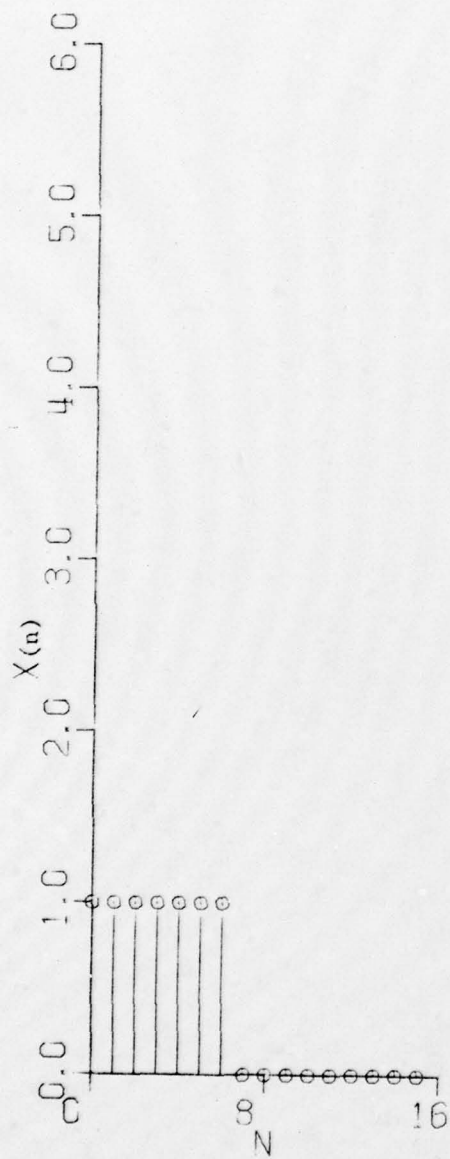


Fig. 11. $x(n)$; 2 Reflections

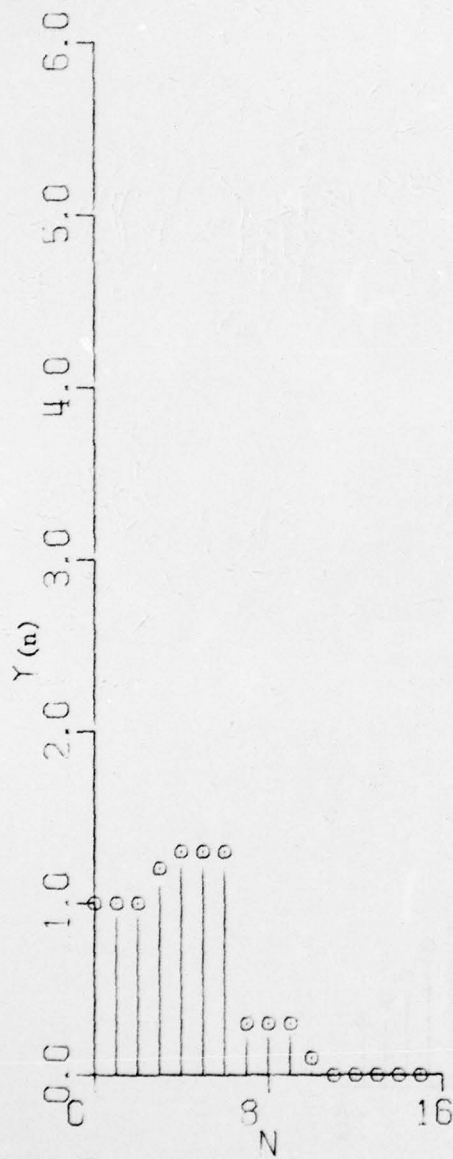


Fig. 12. $y(n) = x(n) + 0.2x(n-3) + 0.1x(n-4)$

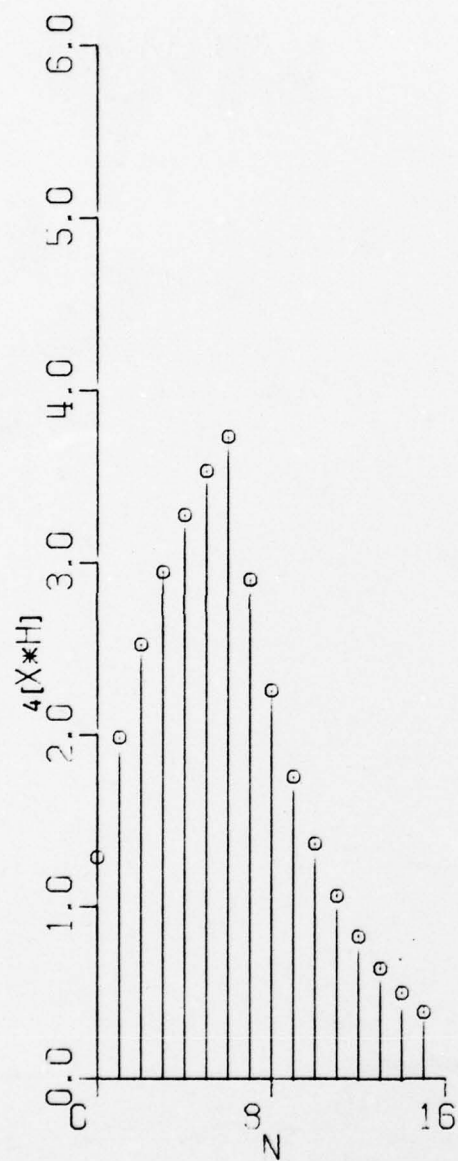


Fig. 13. $4R(n) = 4[x(n)*h(n)]$

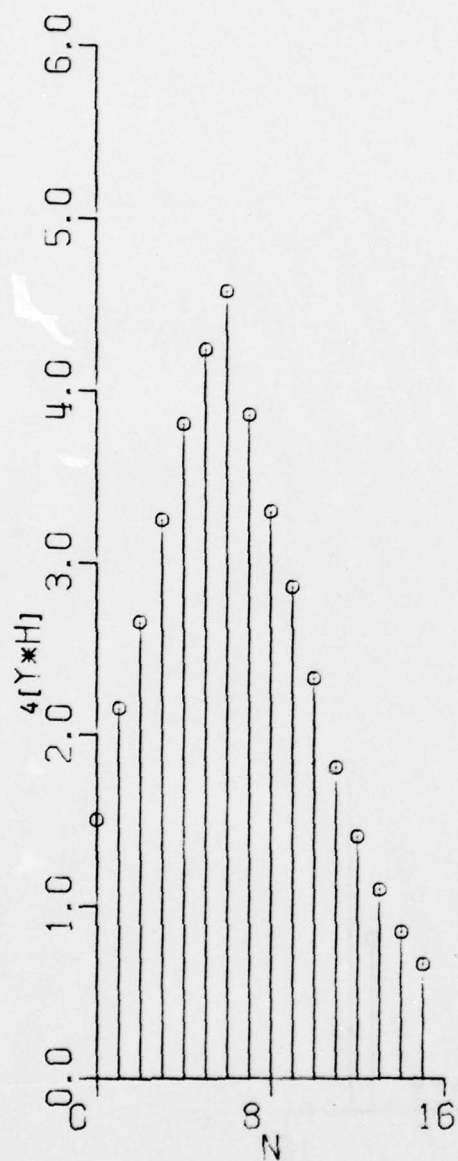


Fig. 14. $4s(n) = 4[y(n)*h(n)]$

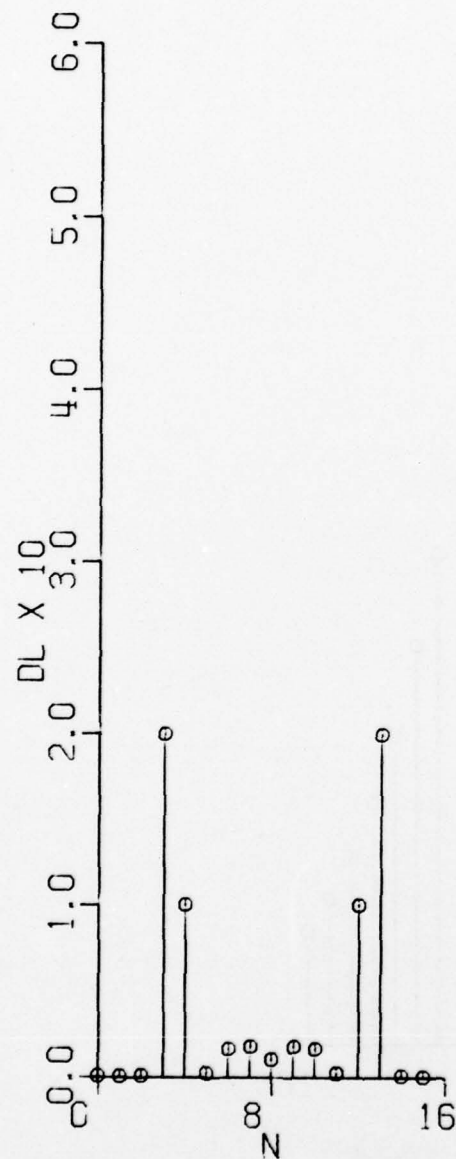


Fig. 15. Cepstrum of $s(n) = h(n)[x(n) + 0.2x(n-3) + 0.1x(n-4)]$ (See $x(n)$ in Fig. 11; see $h(n)$ in Fig. 7.)

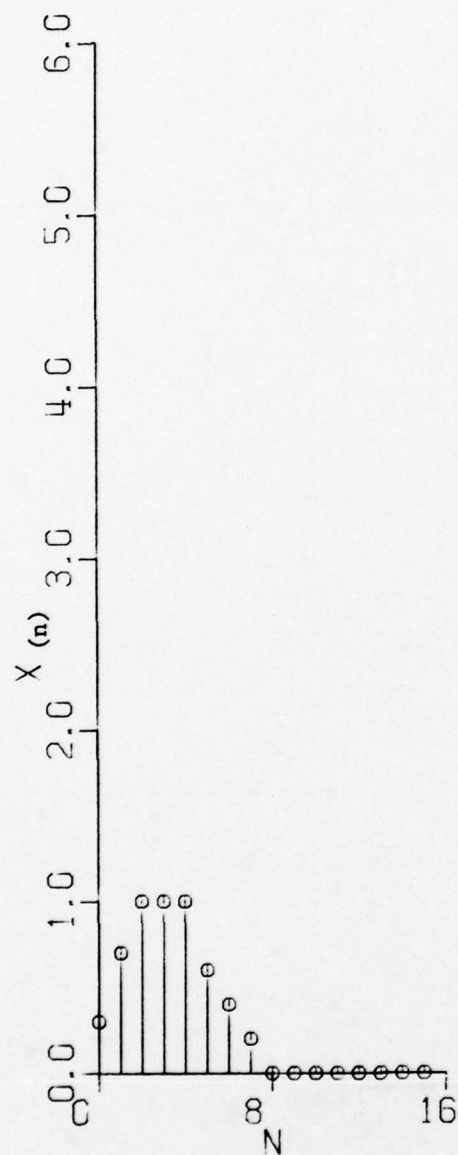


Fig. 16. $x(n)$; Trapezoidal Wave Shape

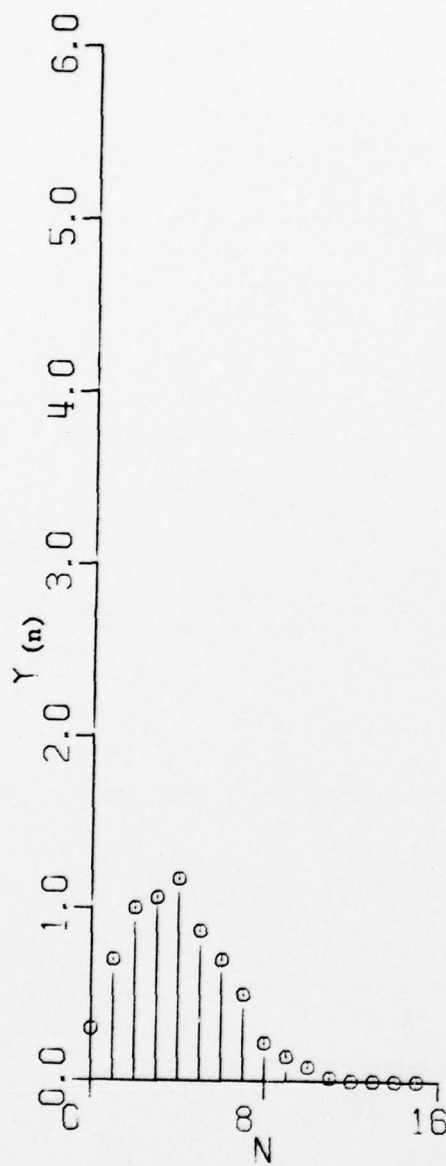


Fig. 17. $y(n)$; Two Reflections; Trapezoidal Input

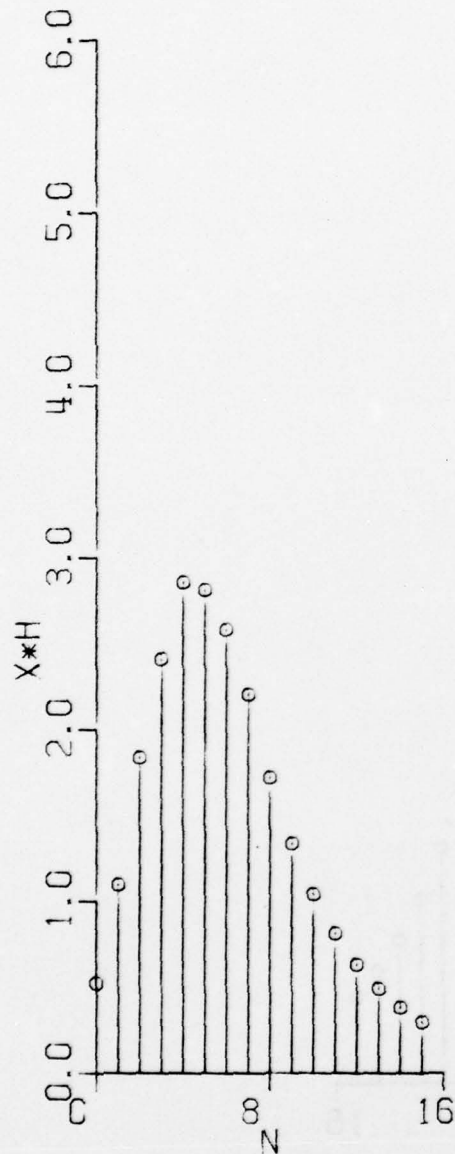


Fig. 18. $4R(n) = 4x(n)*h(n)$; Two Reflections;
Trapezoidal Input

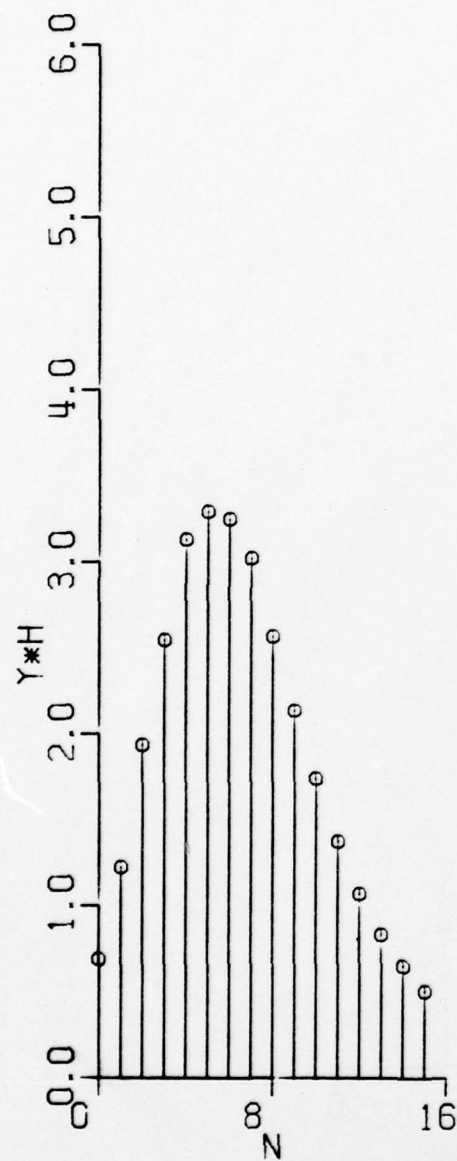


Fig. 19. $4s(n) = 4y(n)*h(n)$; Two Reflections;
Trapezoidal Input

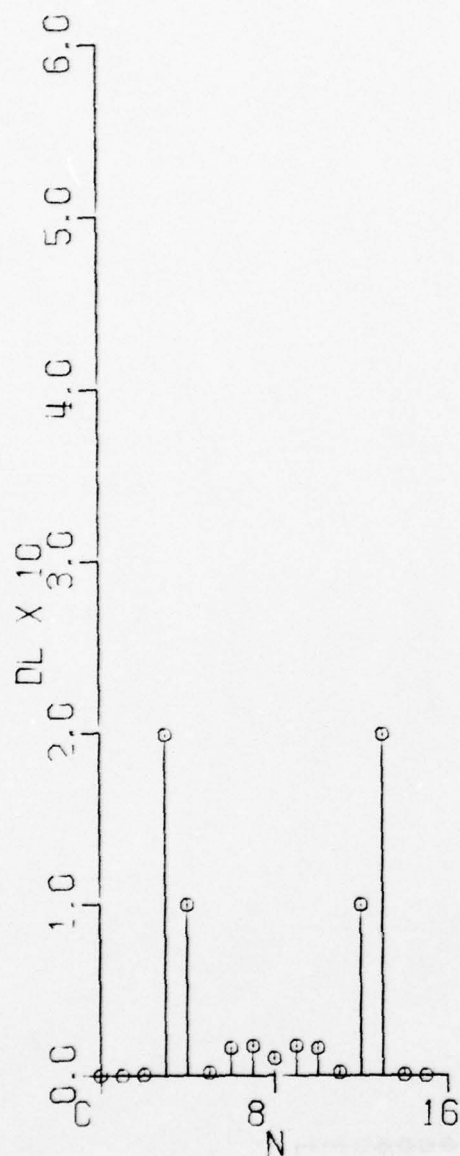


Fig. 20. Real Cepstrum of $s(n) = h(n)[x(n) + 0.2x(n-3) + 0.1x(n-4)]$; Trapezoidal Input

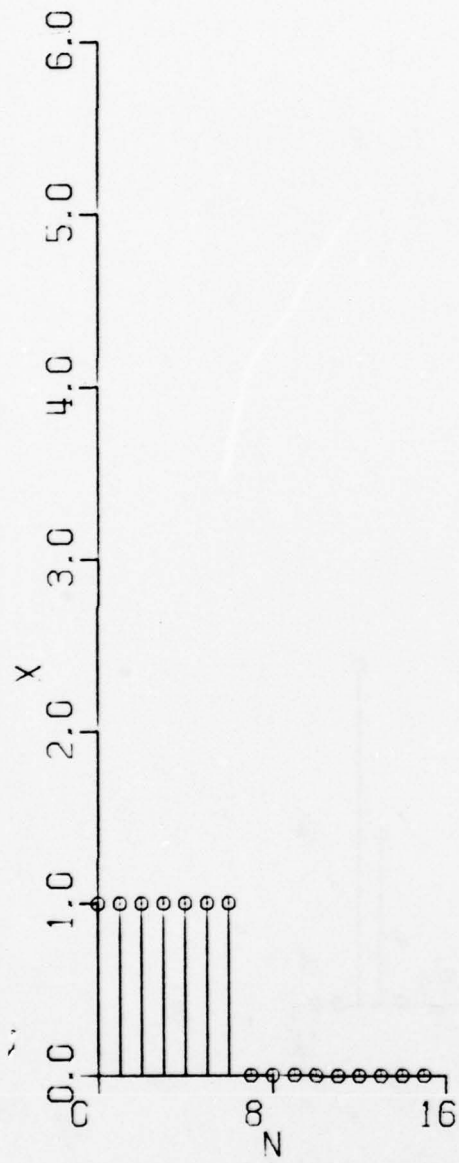


Fig. 21. $x[n]$

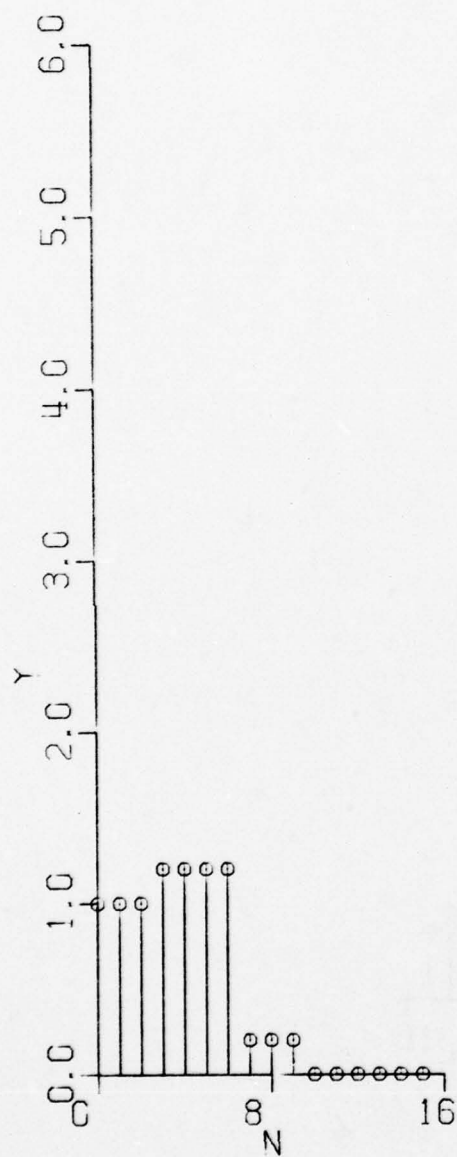


Fig. 22. $y(n)$; One Reflection; Complex Reflection Coefficient

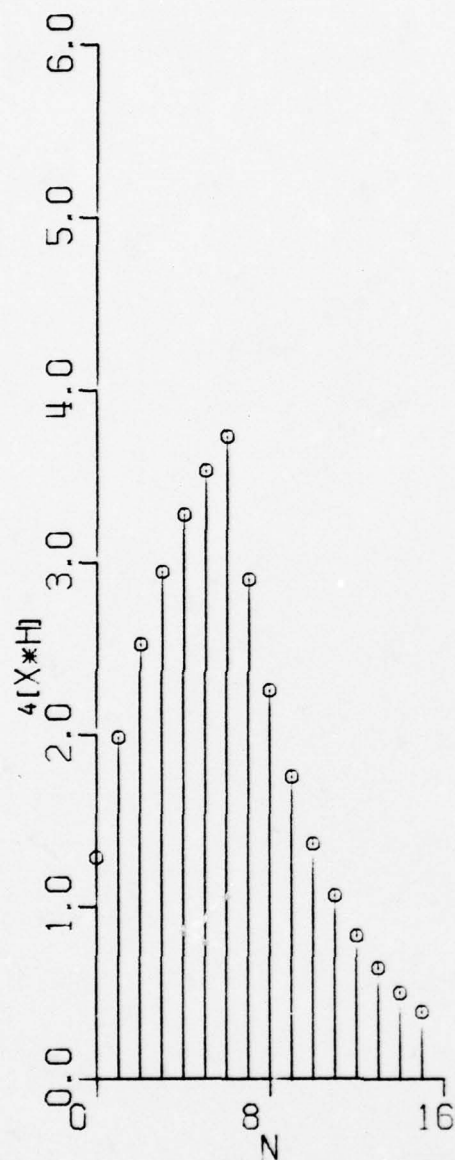


Fig. 23. $4R(n) = 4x(n)*h(n)$



Fig. 24. $4s(n) = 4y(n)*h(n)$

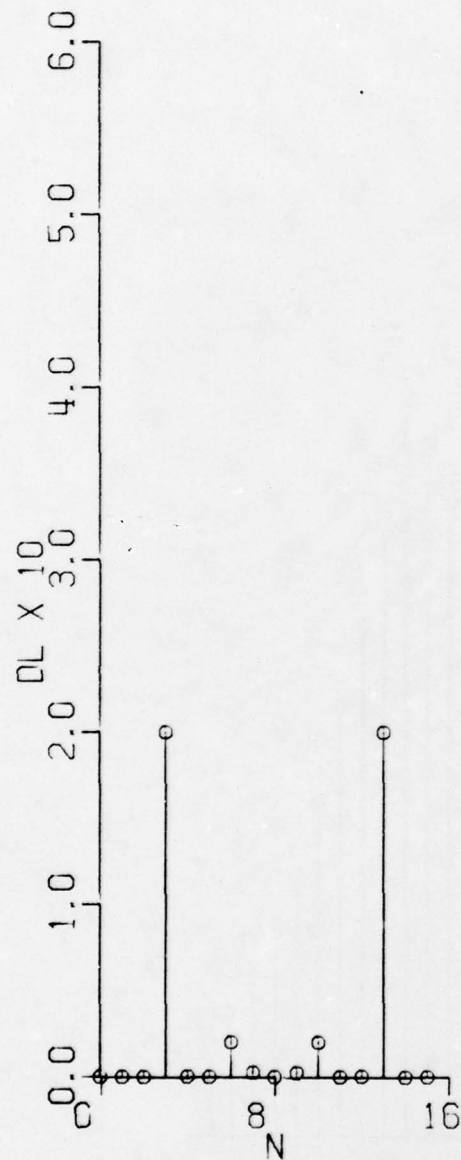


Fig. 25. Real Cepstrum of $s(n) = [x(n) + (0.2 + j0.2)x(n-3)]$

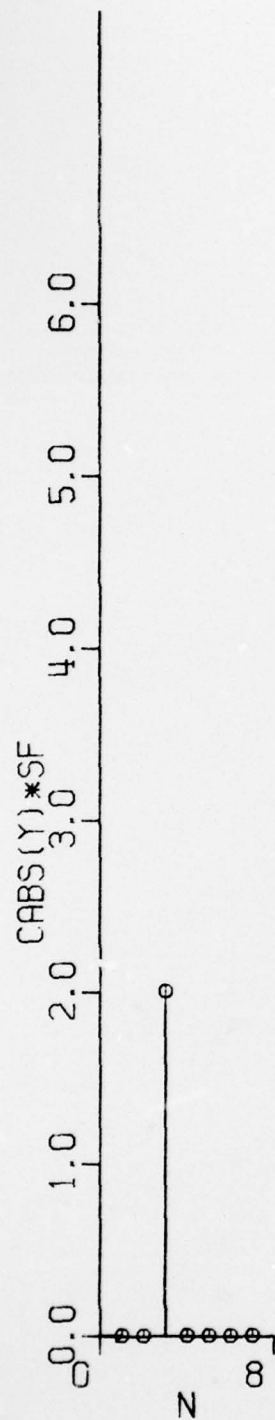


Fig. 26. Delay Determination: $E(\phi) = 1 + 0.2E^{j2\pi(3 \cos\phi)}$
 $A = 0.2$; $d/\lambda = 3$; $N = 8$; $SF = 10$

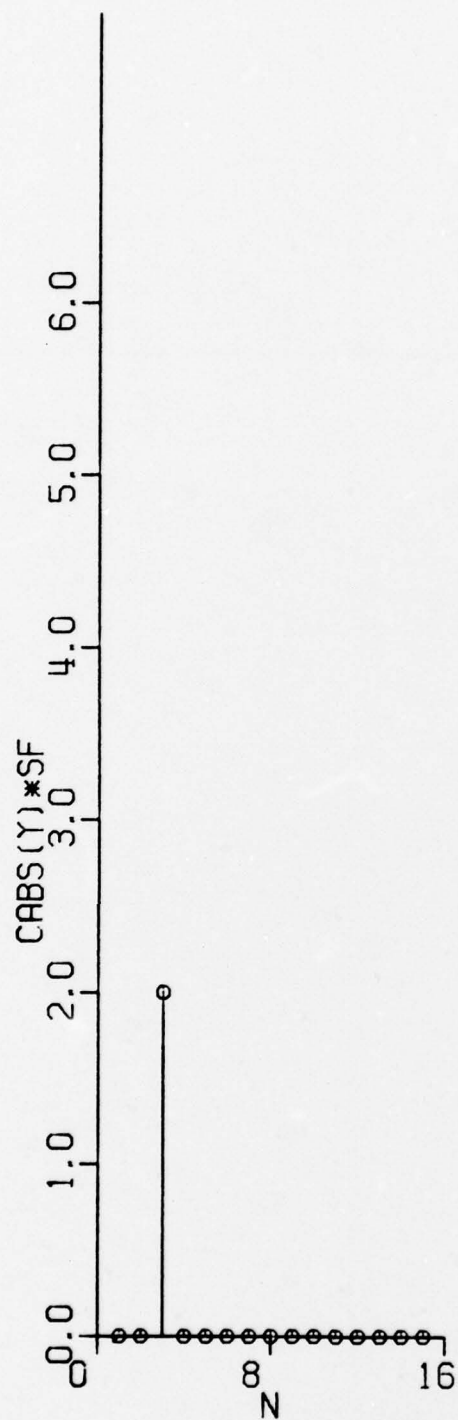


Fig. 27. Delay Determination: $A = 0.2$; $d/\lambda = 3$;
 $N = 16$; $SF = 10$

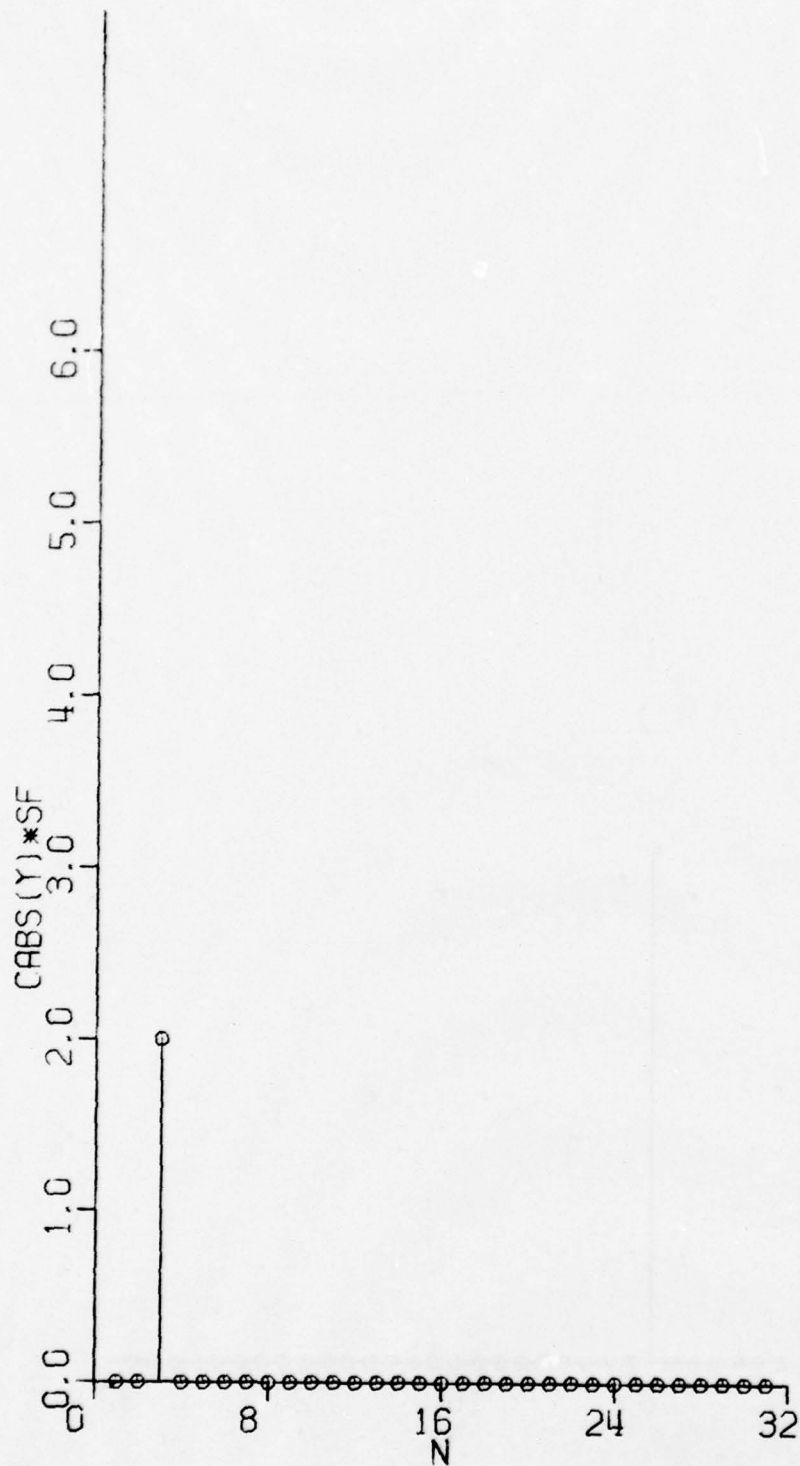


Fig. 28. Delay Determination: $A = 0.2$; $d/\lambda = 3$; $N = 32$;
 $SF = 10$

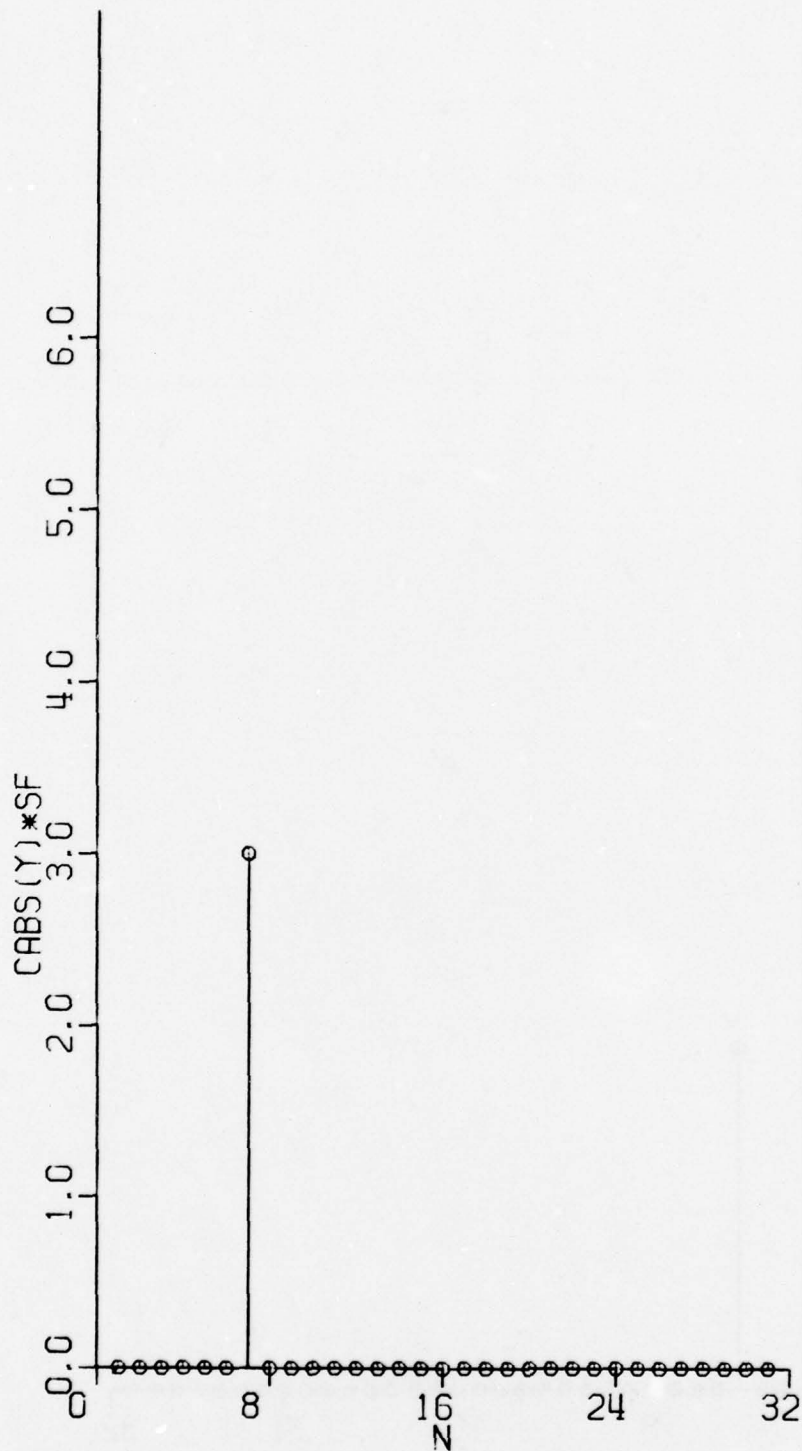


Fig. 29. Delay Determination: $A = 0.3$; $d/\lambda = 7$; $N = 32$; $SF = 10$

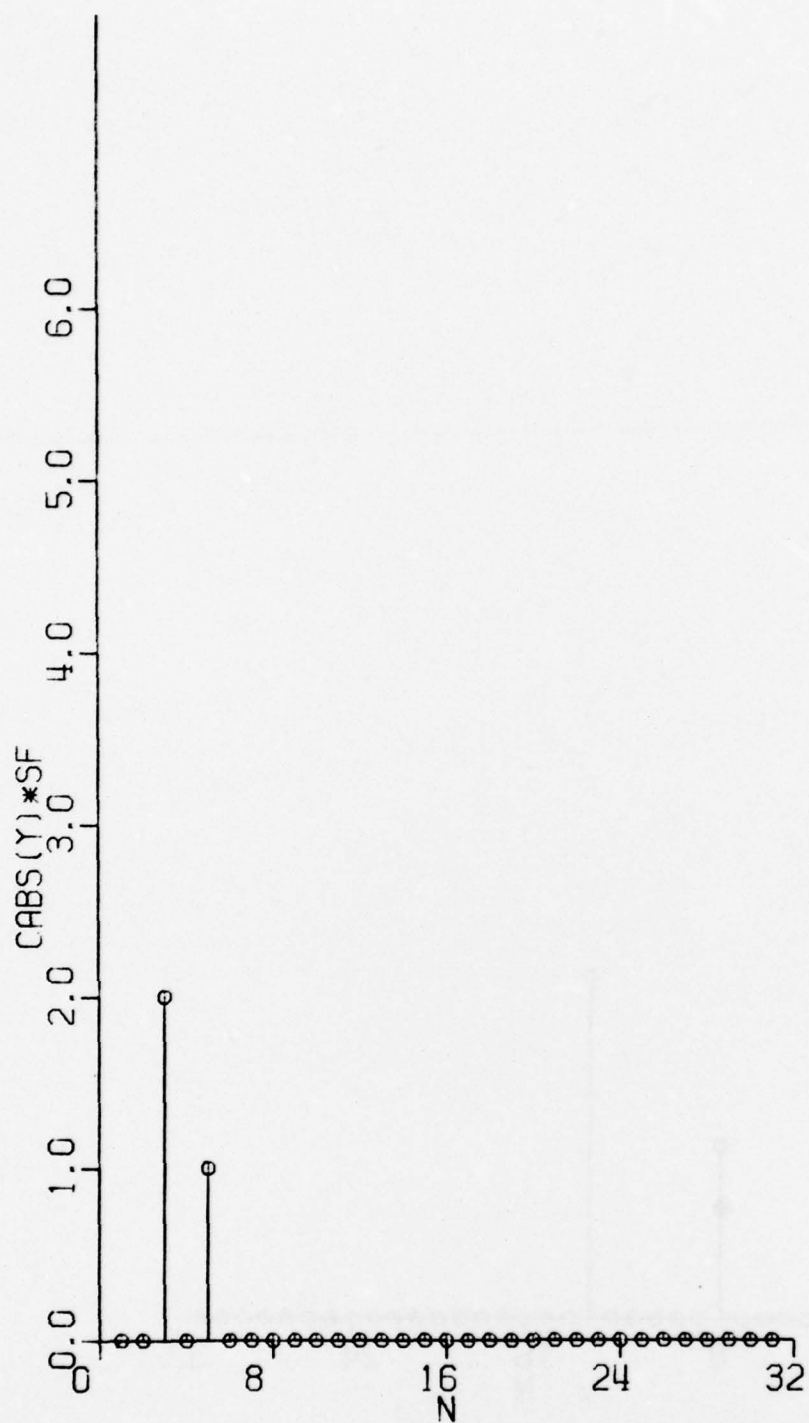


Fig. 30. Delay Determination: $A_1 = 0.2$; $d_1/\lambda = 3$; $A_2 = 0.1$;
 $d_2/\lambda = 6$; $N = 32$; $SF = 10$

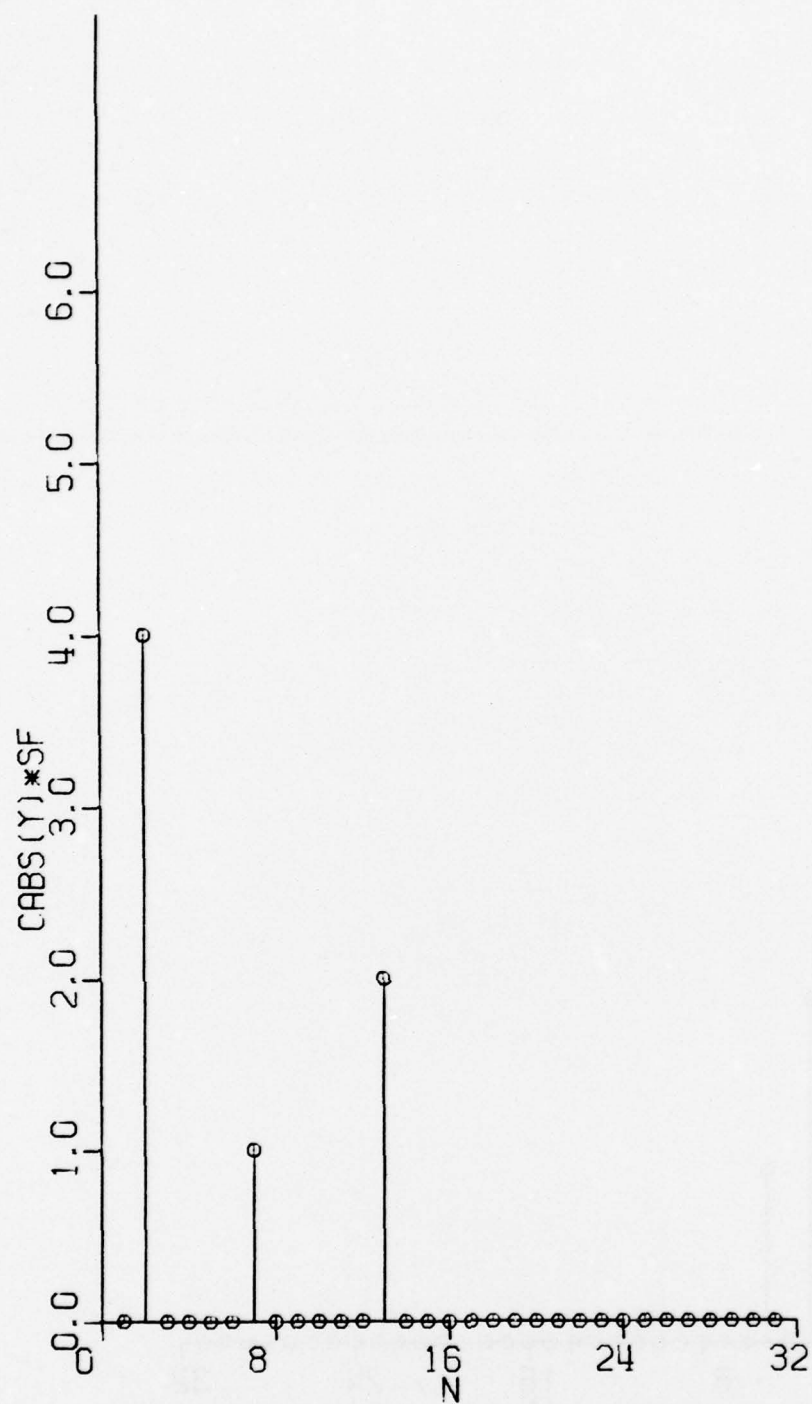


Fig. 31. Delay Determination: $A_1 = 0.4$; $d_1/\lambda = 2$; $A_2 = 0.1$; $d_2/\lambda = 7$; $A_3 = 0.2$; $d_3/\lambda = 13$; $N = 32$; $SF = 10$

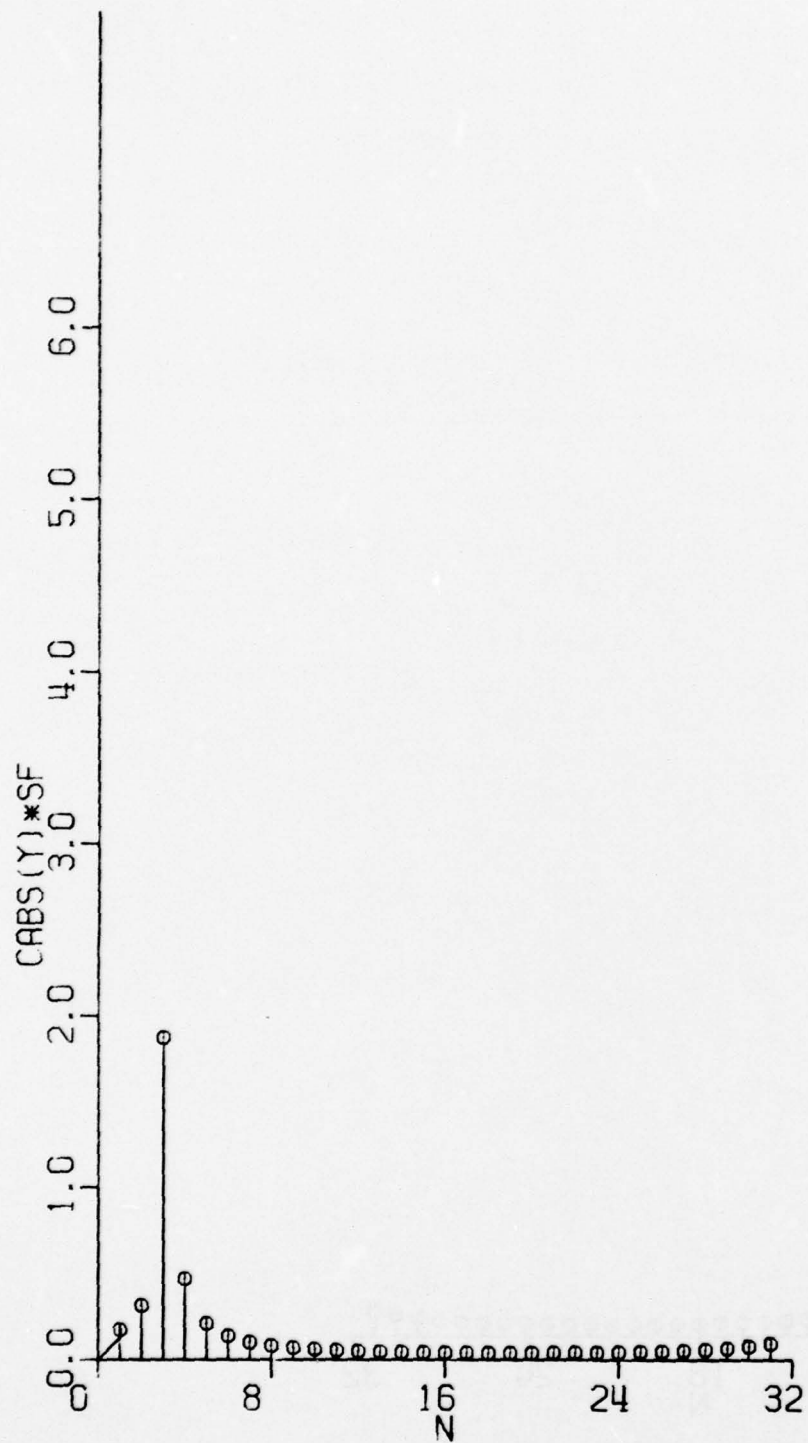


Fig. 32. Delay Determination: $A = 0.2$; $d/\lambda = 3.2$; $N = 32$; $SF = 10$

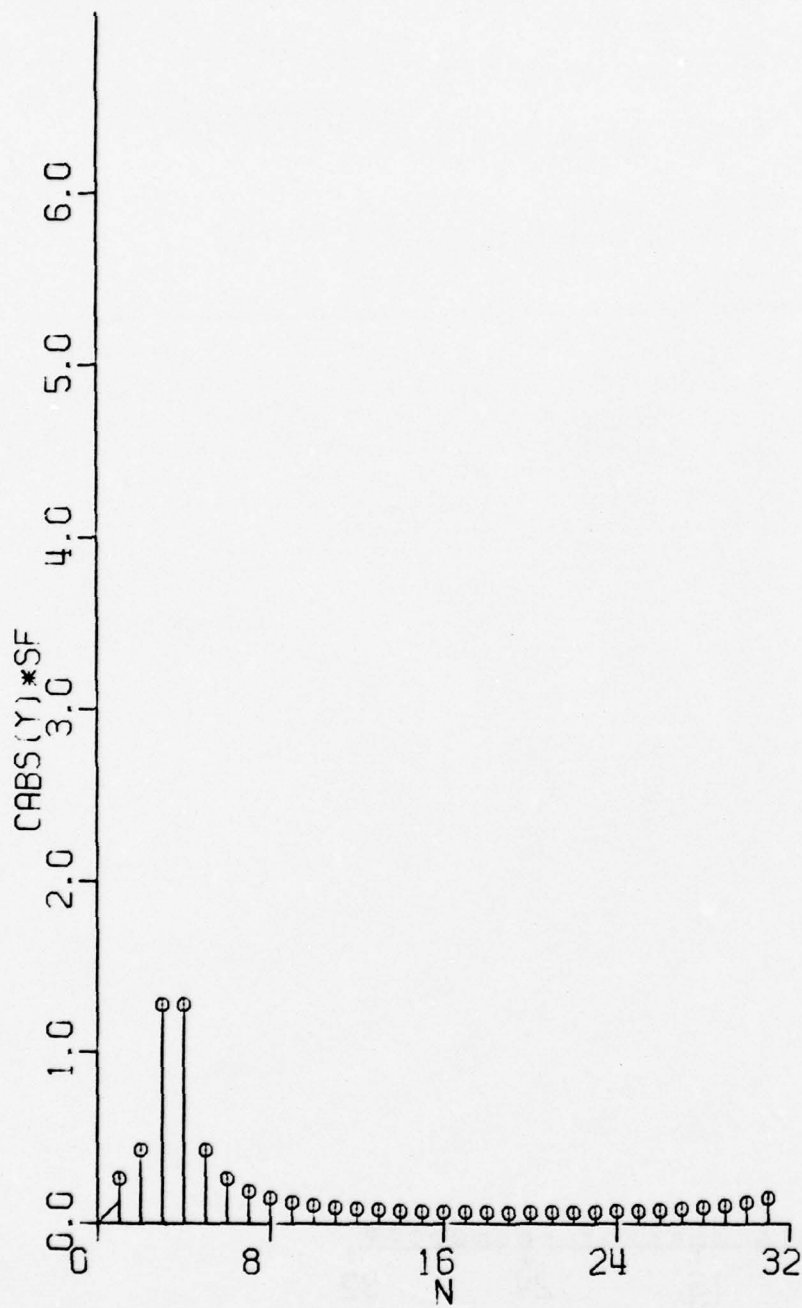


Fig. 33. Delay Determination: $A = 0.2$; $d/\lambda = 3.5$; $N = 32$; $SF = 10$

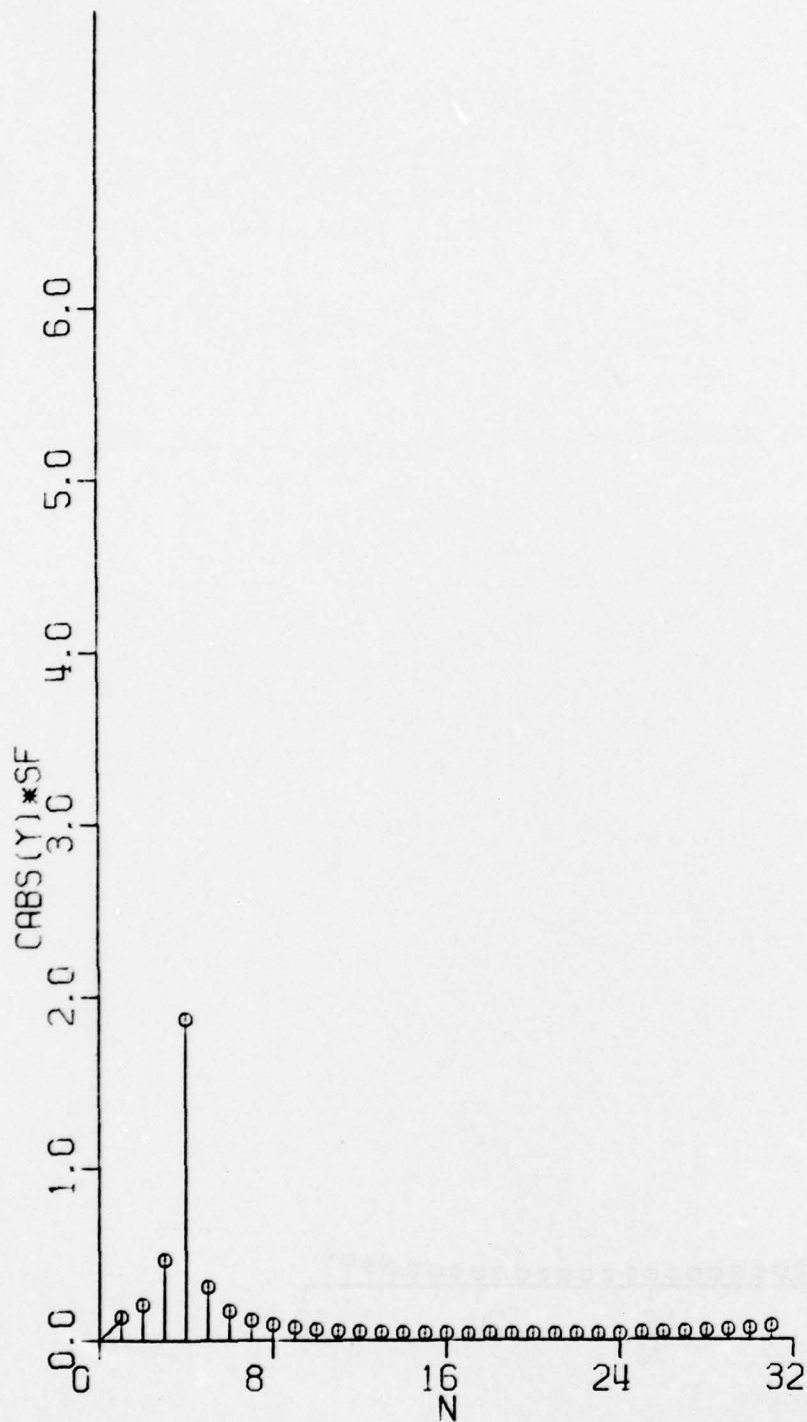


Fig. 34. Delay Determination: $A = 0.2$; $d/\lambda = 3.8$; $N = 32$; $SF = 10$

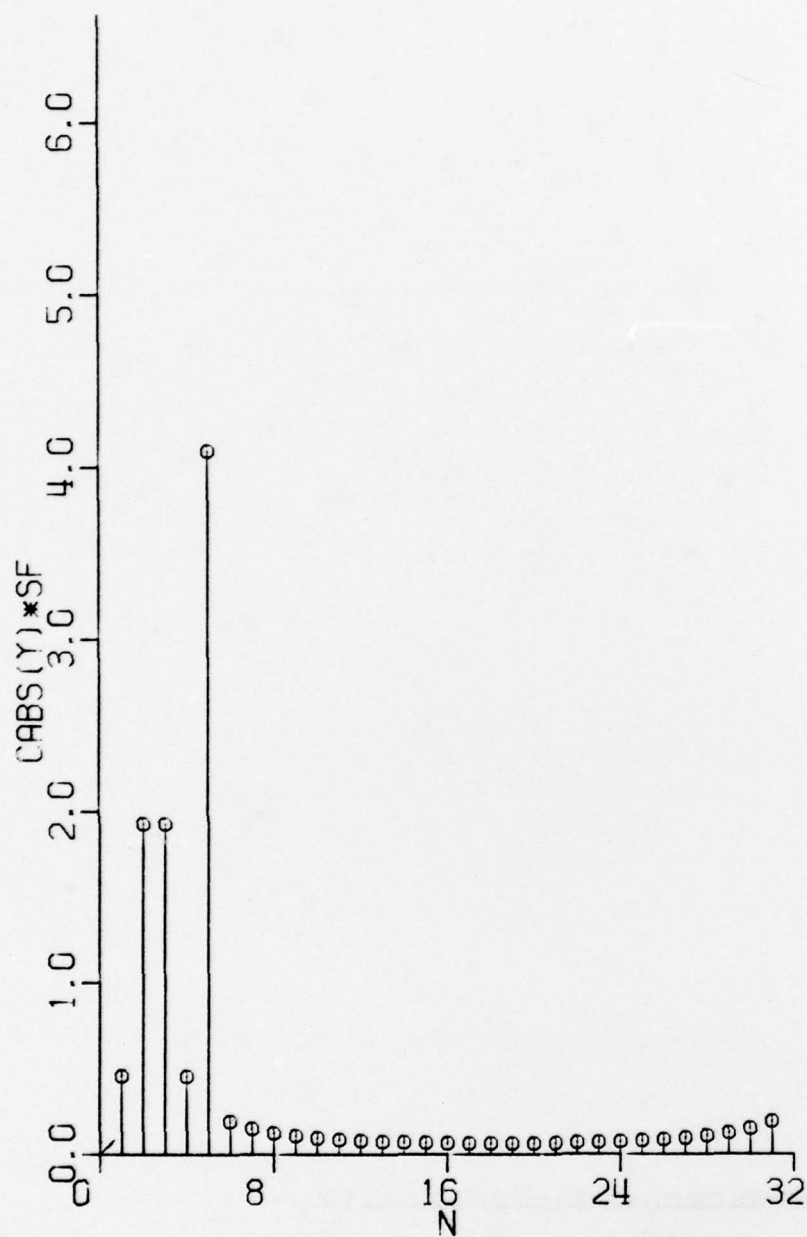


Fig. 35. Delay Determination: $A_1 = 0.2$; $d_1/\lambda = 2.25$; $A_2 = 0.2$; $d_2/\lambda = 2.75$; $A_3 = 0.4$; $d_3/\lambda = 5$; $N = 32$; $SF = 10$

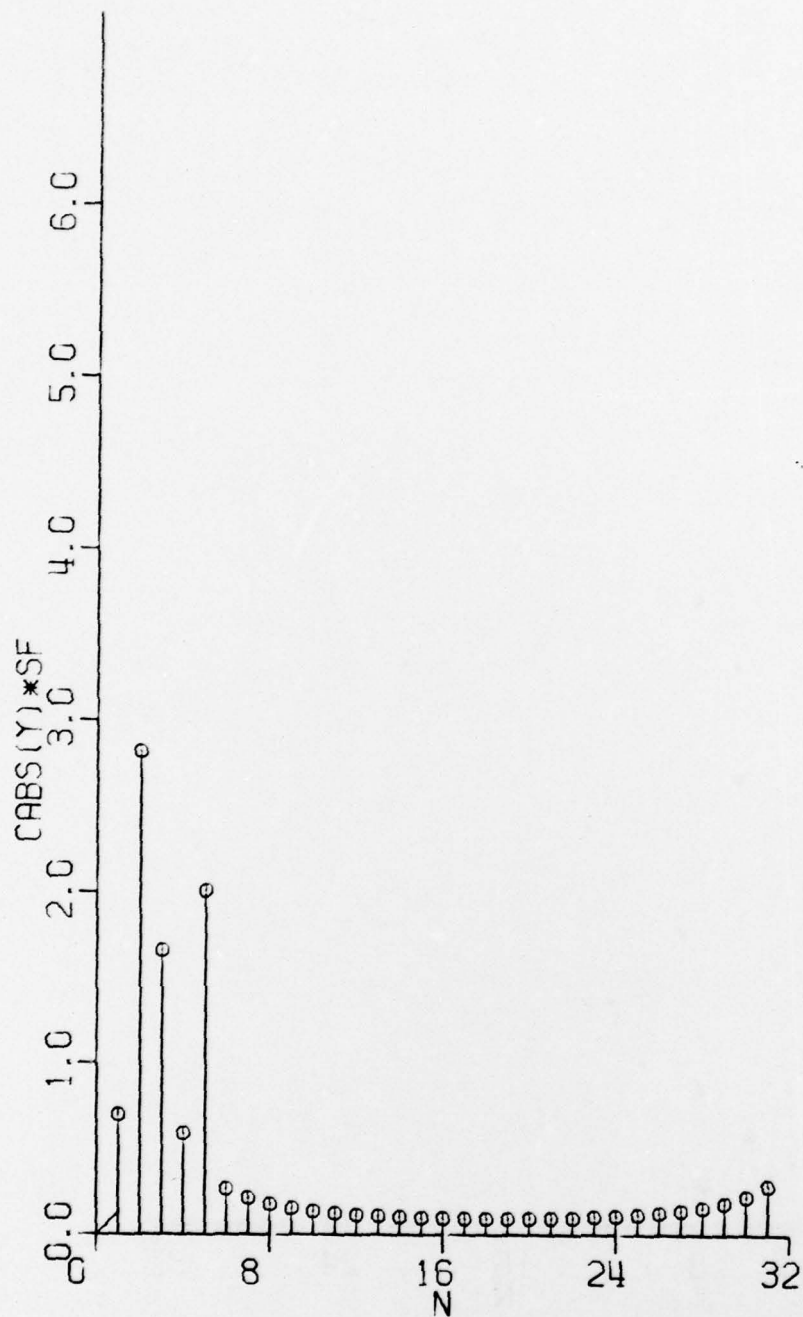


Fig. 36. Delay Determination: $A_1 = 0.3$; $d_1/\lambda = 2.3$;
 $A_2 = 0.1$; $d_2/\lambda = 2.65$; $A_3 = 0.2$; $d_3/\lambda = 5$; $N = 32$; $SF = 10$

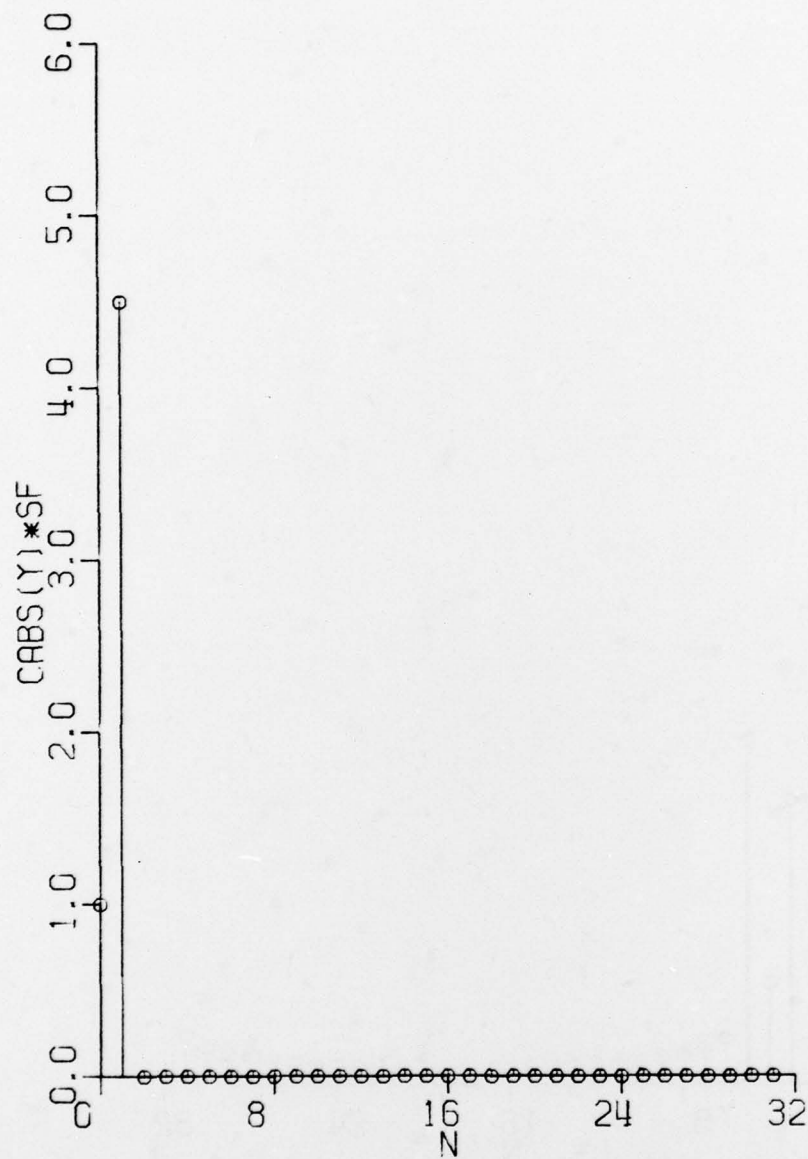


Fig. 37. Delay Determination: Noninteger Program
 $A = 0.45$; $d/\lambda = 3.5$; $N = 32$; $SF = 10$

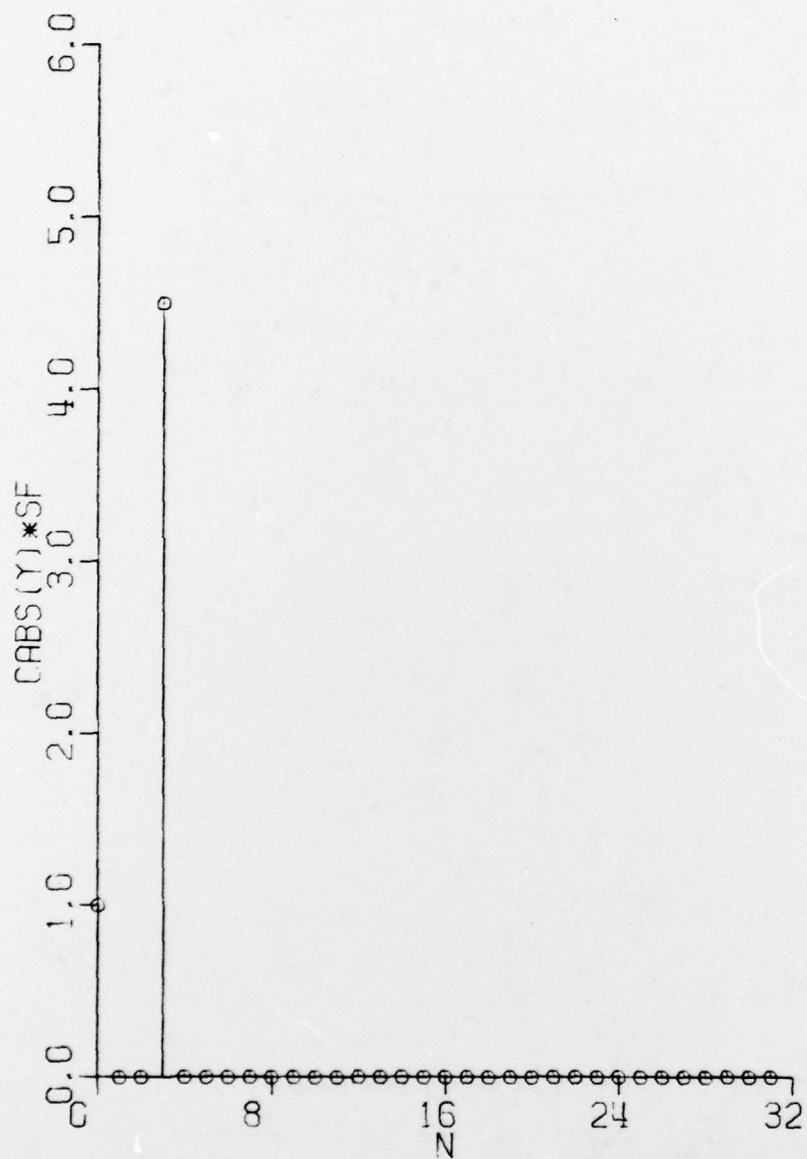


Fig. 38. Delay Determination: Noninteger Program
 $A = 0.45$; $d/\lambda = 10.5$; $N = 32$; $SF = 10$

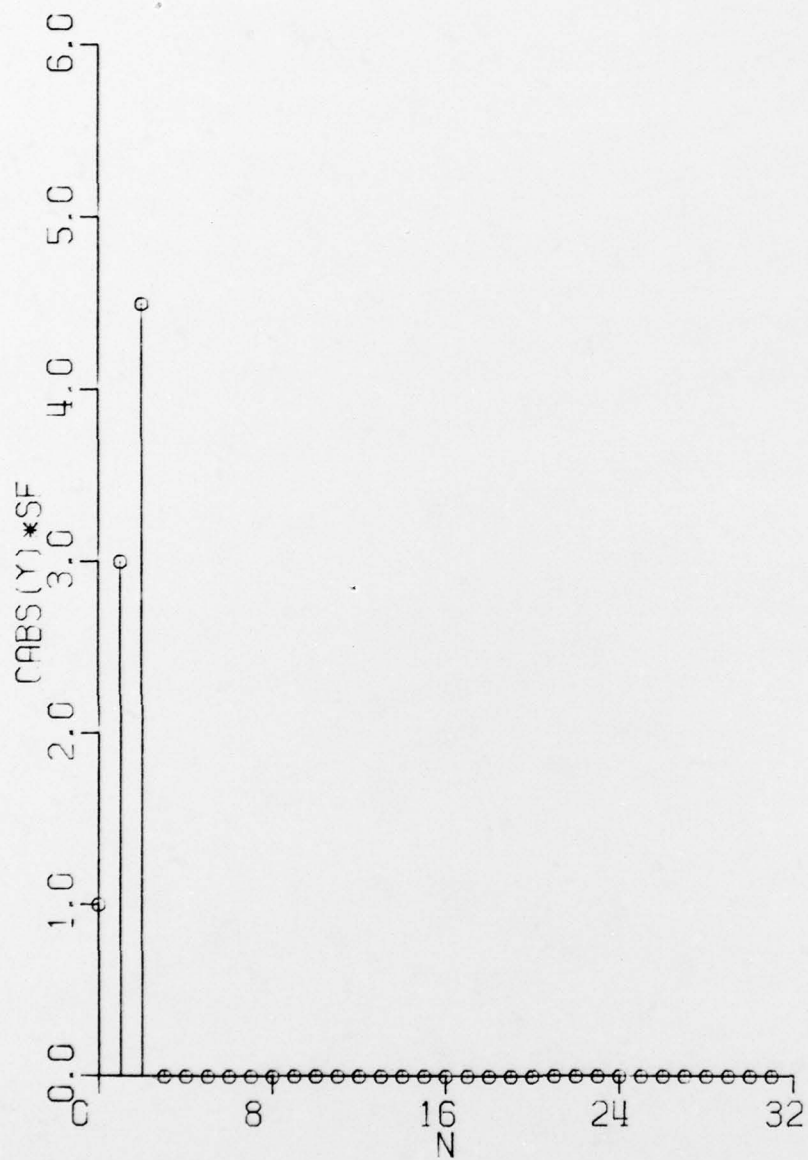


Fig. 39. Delay Determination: Noninteger Program
 $A_1 = 0.3$; $d_1/\lambda = 1.25$; $A_2 = 0.45$; $d_2/\lambda = 2.5$; $N = 32$; $SF = 10$

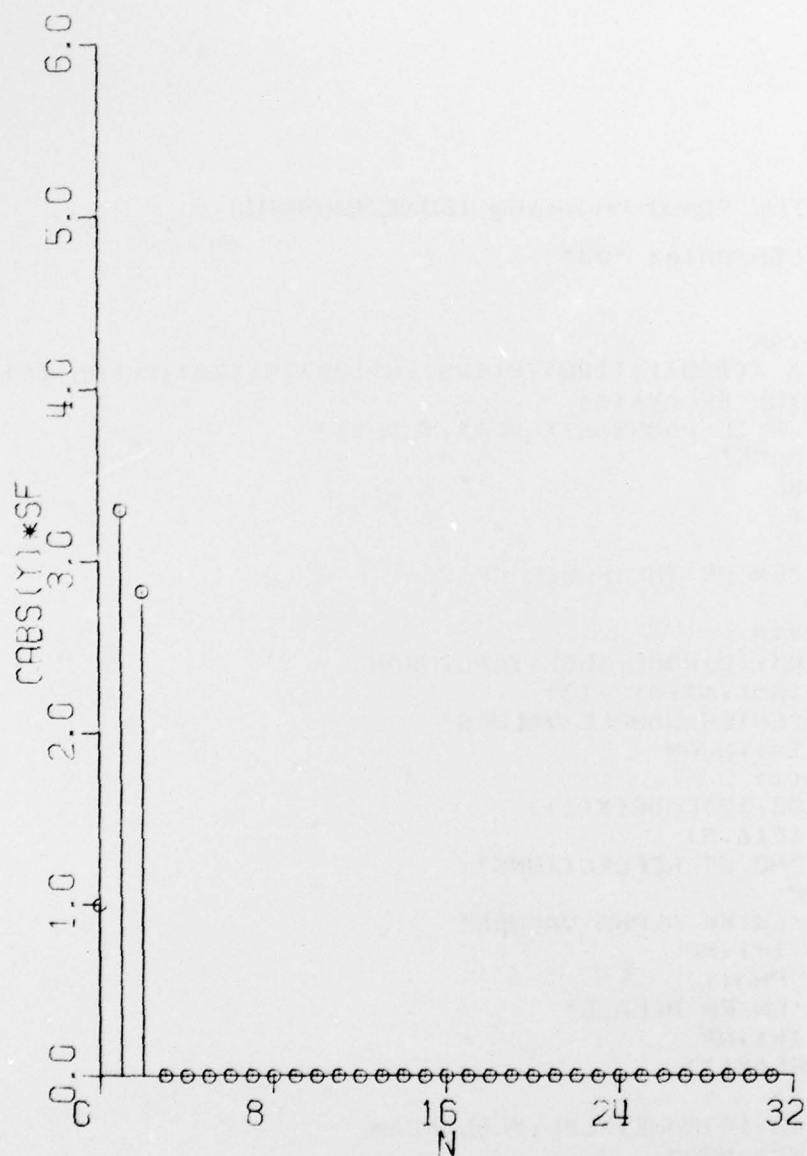


Fig. 40. Delay Determination: Noninteger Program
 $A_1 = 0.33$; $d_1/\lambda = 1.25$; $A_2 = 0.2 + j0.2$; $d_2/\lambda = 2.5$;
 $N = 32$; $SF = 10$

APPENDIX

Computer Program: Time Signal Processing (SILVERMAN/DRSIL)

```
10**RUN= # /RAMESH/DATA3 "03"
20C
30C
40     REAL MN,SF
50     COMPLEX X(128),Y(128),R(128),S(128),H(128),ALPHA(16)
60     DIMENSION DELAY(16)
70     CHARACTER IF,NAME*56,XLBL*1,YLBL*12
80     1 PRINT:'NAME'
90     READ:NAME
100    XLBL='N'
110    YLBL='X'
120    PRINT:'ENTER THE POWER OF 2'
130    READ:M
140    NSAM=2**M
150    WRITE(03,10)NAME,XLBL,YLBL,NSAM
160    10 FORMAT(A56,A1,A12,I3)
170    PRINT:'ENTER SAMPLE VALUES'
180    DO 20 I=1,NSAM
190    READ:X(I)
200    20 WRITE(03,12)CABS(X(I))
210    12 FORMAT(E16.8)
220    PRINT:'NO OF REFLECTIONS'
230    READ:NP
240    PRINT:'ENTER ALPHA VALUES'
250    DO 30 I=1,NP
260    30 READ:ALPHA(I)
270    PRINT:'ENTER DELAYS'
280    DO 40 I=1,NP
290    40 READ:DELAY(I)
300    YLBL='Y'
310    WRITE(03,10)NAME,XLBL,YLBL,NSAM
320    DO 60 N=1,NSAM
330    SUM=0
340    DO 50 I=1,NP
350    NT=N-DELAY(I)
360    IF(NT) 45,45,47
370    45 MN=0
380    GO TO 50
390    47 MN=ALPHA(I)*X(NT)
400    50 SUM=SUM+MN
410    Y(N)=X(N)+SUM
```


(SILVERMAN/DRSIL) continued

```
420 60 WRITE(03,12)CABS(Y(N))
430 PRINT:"X(N) VALUES ARE"
440 PRINT:(X(I),I=1,NSAM)
450 PRINT:"Y(N) VALUES ARE"
460 PRINT:(Y(N),N=1,NSAM)
470 CALL FFT(X,M)
480 CALL FFT(Y,M)
530 YLBL='H'
540 WRITE(03,10)NAME,XLBL,YLBL,NSAM
550 DO 70 I=1,NSAM
560 H(I)=EXP(-0.25*(I-1))
570 70 WRITE(03,12)CABS(H(I))
580 PRINT:"H VALUES ARE"
590 PRINT:(H(I),I=1,NSAM)
600 CALL FFT(H,M)
630 DO 80 I=1,NSAM
640 R(I)=X(I)*H(I)
650 X(I)=ABS(R(I))
660 X(I)=X(I)*X(I)
670 IF(X(I).EQ.0) X(I)=0.0000000001
680 X(I)=ALOG(X(I))
690 S(I)=Y(I)*H(I)
700 Y(I)=ABS(S(I))
710 80 Y(I)=ALOG(Y(I)*Y(I))
720 YLBL='X*H'
725 CALL INVFT(R,M)
730 WRITE(03,10)NAME,XLBL,YLBL,NSAM
740 WRITE(03,12)(CABS(R(I)),I=1,NSAM)
760 CALL INVFT(S,M)
770 YLBL='Y*H'
780 WRITE(03,10)NAME,XLBL,YLBL,NSAM
790 WRITE(03,12)(CABS(S(I)),I=1,NSAM)
800 CALL INVFT(X,M)
810 CALL INVFT(Y,M)
820 PRINT:"THE RESULTS ARE ....."
830 YLBL='DL X 10'
840 WRITE(03,10)NAME,XLBL,YLBL,NSAM
850 DO 90 I=1,NSAM
860 X(I)=Y(I)-X(I)
870 WRITE(03,12)CABS(X(I)*10)
880 90 PRINT:X(I),I
930 PRINT:"FINISHED? ENTER 'YES' TO STOP, 'NO' TO CONTINUE"
940 READ:IF
950 IF (IF.EQ."NO") GO TO 1
960 STOP
970 END
```

(SILVERMAN/DRSIL) continued

```
980      SUBROUTINE FFT(X,M)
990      COMPLEX X(128),U,W,T
1000      N=2**M
1010      NV2=N/2
1020      NM1=N-1
1030      J=1
1040      DO 7 I=1,NM1
1050      IF(I.GE.J) GO TO 5
1060      T=X(J)
1070      X(J)=X(I)
1080      X(I)=T
1090      5 K=NV2
1100      6 IF(K.GE.J) GO TO 7
1110      J=J-K
1120      K=K/2
1130      GO TO 6
1140      7 J=J+K
1150      PI=3.14159265358979
1160      DO 20 L=1,M
1170      LE=2**L
1180      LE1=LE/2
1190      U=1.
1200      W=CMPLX(COS(PI/FLOAT(LE1)), -SIN(PI/FLOAT(LE1)))
1210      DO 20 J=1,LE1
1220      DO 10 I=J,N,LE
1230      IP=I+LE1
1240      T=X(IP)*U
1250      X(IP)=X(I)-T
1260      10 X(I)=X(IP)+T
1270      20 U=U*W
1280      RETURN
1290      END
1300      SUBROUTINE INVFT(X,M)
1310C*X IS THE ARRAY CONTAINS THE TRANSFORM INITIALLY
1320C* AND FINALLY CONTAINS THE SEQUENCE.
1330      COMPLEX X(128),U,W,T
1340      N=2**M
1350      NV2=N/2
```

(SILVERMAN/DRSIL) continued

```
1360      NM1=N-1
1370      J=1
1380      DO 7 I=1,NM1
1390      IF(I.GE.J) GO TO 5
1400      T=X(J)
1410      X(J)=X(I)
1420      X(I)=T
1430      5 K=NV2
1440      6 IF(K.GE.J) GO TO 7
1450      J=J-K
1460      K=K/2
1470      GO TO 6
1480      7 J=J+K
1490      PI=3.14159265358979
1500      DO 20 L=1,M
1510      LE=2**L
1520      LE1=LE/2
1530      U=1.
1540      W=CMPLX(COS(PI/FLOAT(LE1)),SIN(PI/FLOAT(LE1)))
1550      DO 20 J=1,LE1
1560      DO 10 I=J,N;LE
1570      IP=I+LE1
1580      T=X(IP)*U
1590      X(IP)=X(I)-T
1600      10 X(I)=X(I)+T
1610      20 U=U*W
1620      FN=N
1630      DO 30 I=1,N
1640      X(I)=X(I)/FN
1650      30 CONTINUE
1660      RETURN
1670      END
```

Computer Program: Radiation Pattern Processing (NYAKA/CEPMLD)

```
10**RUN= # /RAMESH/DATA1 *03*
20      SUBROUTINE INVFT(X,M)
30C*X IS THE ARRAY CONTAINS THE TRANSFORM INITIALLY
40C* AND FINALLY CONTAINS THE SEQUENCE.
50      COMPLEX X(128),U,W,T
60      N=2**M
70      NV2=N/2
80      NM1=N-1
90      J=1
100     DO 7 I=1,NM1
110     IF(I.GE.J) GO TO 5
120     T=X(J)
130     X(J)=X(I)
140     X(I)=T
150     5 K=NV2
160     6 IF(K.GE.J) GO TO 7
170     J=J-K
180     K=K/2
190     GO TO 6
200     7 J=J+K
210     PI=3.14159265358979
220     DO 20 L=1,M
230     LE=2**L
240     LE1=LE/2
250     U=1.
260     W=CMPLX(COS(PI/FLOAT(LE1)),SIN(PI/FLOAT(LE1)))
270     DO 20 J=1,LE1
280     DO 10 I=J,N,LE
290     IP=I+LE1
300     T=X(IP)*U
310     X(IP)=X(I)-T
320     10 X(I)=X(I)+T
330     20 U=U*W
340     FN=N
350     DO 30 I=1,N
360     X(I)=X(I)/FN
370     30 CONTINUE
380     RETURN
390     END
400     SUBROUTINE PATTN(E,X)
410C*THIS COMPUTES FIELD PATTERN AT ANGLES PHI
420     COMMON A,DL,M,NR
430     INTEGER M,NR,KI
```


(NYAKA/CEPMLD)

```
440      REAL X(128),DL(10)
450      COMPLEX A(10),E(128),ESKI
460      N=2**M
470      PI=3.14159265358979
480      DO 20 I=1,N
490      E(I)=CMPLX(1.0,0.0)
500      DO 10 K=1,NR
510      KI=K*I
520      BKI=2.0*PI*DL(K)*X(I)
530      ESKI=A(K)*CMPLX(COS(BKI),-SIN(BKI))
540      E(I)=E(I)+ESKI
550 10    CONTINUE
560 20    CONTINUE
570      RETURN
580      END
590C     MAIN PROGRAM
600 1     PRINT: " "
610      READ: NUMBER
620      PRINT: "                                PLOT #", NUMBER
630      COMMON A,DL,M,NR
640      REAL Z(128),R(128),X(128),DL(10),SF
650      COMPLEX A(10),E(128),Y(128)
660      CHARACTER IF,NAME*56,XLBL*1,YLBL*12
670      PRINT: "N=2**M; ENTER 'M' "
680      READ: M
690      N=2**M
700      PRINT: " # OF REFLECTIONS "
710      READ: NR
712      PRINT: "VALUE OF L"
714      READ: L
716      IF(L) 25,22,25
718 22    L=N
720 25    DO 30 I=1,N
730      XM=I-1
740      X(I)=XM/L
750 30    CONTINUE
760      PRINT: "VALUES OF A(I)?"
770      DO 31 J=1,NR
780 31    READ: A(J)
790      PRINT: "VALUES OF DL(I)?"
800      DO 32 J=1,NR
```

(NYAKA/CEPMLD) continued

```
810 32 READ:DL(J)
820    CALL PATTN(E,X)
830    DO 33 I=1,N
840      IL=I
850 33 CONTINUE
860    DO 35 I=1,N
870      IL=I
880      Y(I)=E(I)
890 35 CONTINUE
900    CALL INVFT(Y,M)
910    PRINT:"SCALE FACTOR"
920    READ:SF
930C*Y(I) WILL BE FINAL SEQUENCE OF COMPOSITE FIELD
940    XLBL="N"
950    YLBL="CABS(Y)*SF"
960    PRINT:"NAME"
970    READ:NAME
980    WRITE(03,37) NAME,XLBL,YLBL,N
990 37 FORMAT(A56,A1,A12,I3)
1000    DO 40 I=1,N
1010      IN=I
1020      PRINT:(IN-1),CABS(Y(IN)),Y(IN)
1022      YIN=CABS(Y(IN))
1024      IF(YIN-0.5) 38,38,39
1026 38 YIN=YIN*SF
1030 39 WRITE(03,45) YIN
1040 45 FORMAT(E16.8)
1050 40 CONTINUE
1060    PRINT:"FINISHED? ENTER 'YES' TO STOP, 'NO' TO CONTINUE"
1070    READ:IF
1080    IF(IF.EQ."NO") GO TO 1
1090    STOP
1100    END
```

Computer Program: Plotter Routine (RAMESH/PLTCP3)

```

1##N,J
20$ IDENT BLA00001,PERINI-RM,956700160121,PLTCP3
30$ OPTION FORTRAN
40$ FORTY
50 DIMENSION X(500),Y(500)
60 CHARACTER NAME*56,XLBL*1,YLBL*12,USER*9
70 CALL INITAL(26,500,12,1,0,0)
80 USER='PERINI-NY'
90 101 READ(03,1,END=100) NAME,XLBL,YLBL,N
100 1 FORMAT(A56,A1,A12,I3)
110 READ(03,3) (Y(I),I=1,N)
120 3 FORMAT(E16.8)
130 CALL RSTR(2)
140 XAXIS=N*0.125
150 YAXIS=6.0
160 CALL PLOT(2.0,2.5,-3)
170 CALL SYMBOL(-1.0,-2.0,.56,USER,90.0,9)
200 CALL AXIS(0.,0.,XLBL,-1,XAXIS,0.,0.,8.0,-1)
210 CALL AXIS(0.,0.,YLBL,+12,YAXIS,90.,0.,1.0,1)
215 CALL PLOT(0.,Y(1),3)
216 CALL MARKER(1)
217 CALL PLOT(0.,0.,2)
220 DO 10 I=2,N
223 X(I)=0.125*(I-1)
224 CALL PLOT(X(I),Y(I),3)
225 CALL MARKER(1)
226 CALL PLOT(X(I),0.,2)
227 10 X(I)=X(I)+0.125
230 CALL SYMBOL(-.75,-2.0,.14,NAME,0.0,56)
240 GO TO 101
250 100 CALL RSTR(2)
260 STOP
270 END
280$ SELECT LIBRARY/COMLOT
290$ EXECUTE
300$ MSG2 1,PLEASE RUN TAPE THROUGH PLOTTER
310$ MSG2 1,AT COMPLETION OF THIS JOB
320$ LIMITS 30,20K,,
330$ FFILE 26,NSTDLB,NOSRLS,FXLNG/226,NOSLEW,BUFSIZ/226
340$ TAPE9 26,X1D,,46725,,SUPLOT-SW,,DEN8
350$ PRMFL 03,R/W,S,BLA00001/RAMESH/DATA3
360$ ENDJOB

```


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