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Electrostatic Target Detection:
A Preliminary Investigation

by

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January 30, 1994

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This report investigates the applicability of a time-domain technique to estimate the fuzing location in the electrostatic detection problem. This preliminary study is restricted to the case of an ideal point charge response for a short circuit longitudinal sensor, and a given miss distance. The procedure uses a combination of a linear smoothing filter and a non-linear median filter to estimate the fuzing location in noisy conditions. The robustness of the technique to additive white noise distortions is also investigated. Initial results show that the time-domain analysis technique is promising; the error obtained in the estimation may be kept to within 10% of the true fuzing location for a Signal-to-Noise Ratio (SNR) greater than 5.41 dB (i.e., for an additive noise power less than 0.019) in 86% of the distortion levels investigated.

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ELECTROSTATIC TARGET DETECTION: A PRELIMINARY INVESTIGATION

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Figure 14.1 Frequency spectrum of the colored noise presented in Figure 14. Fc is the center frequency in Hertz, fs is the sampling frequency in Hertz, Q is the quality factor, and N is the order of the FIR filter.

1. INTRODUCTION

All objects in an atmospheric environment have a potential associated with them. This charge is usually much larger for moving airborne objects than for stationary (ground contacting) objects. This report presents preliminary results obtained during Fall 1993 in the area of Electrostatic Target Detection. This preliminary study investigates the application of time-domain filtering methods to estimate the "optimum" fuzing location and studies the robustness of the method to white noise degradation.

Section 2 presents the problem set-up. Section 3 describes the methodology investigated during this preliminary study, its robustness in the presence of additive white noise and presents a methodology for colored noise generation. Finally, Section 4 presents recommendations for further research.

2. PROBLEM SET-UP

Powered and moving objects tend to charge electrostatically due to combination of different charging processes. This charge is usually much larger for airborne objects than for ground contacting objects. Measurements and some preliminary experiments have shown that, under ideal conditions, one can sense the presence of objects of interest using electrostatic sensors (ESS). In this preliminary study we use the point charge response of a short-circuit longitudinal sensor to enhance the detectability of moving objects, that is detection prior to passing the object under ideal and noisy conditions [1]. The information available for the proximity fusing sensing scheme is the differentiated field in the direction of the projectile. An example for a typical Electrostatic point-charge response is given in Figure 1, and further details regarding its expression can be found in Section 3. One key feature was determined to be the position of the zero-crossing [1]. As a result, we concentrated in estimating the location of the zero-crossing in this preliminary study, and investigated the robustness of the technique to noise degradation

The main motivation behind the choice of the technique investigated in the preliminary study lies in its simplicity, as it can be implemented real-time and with a minimum of hardware. Estimating the position of the zero-crossing when no noise is present is a very basic problem. However, for practical applications one has to deal with noisy responses, such as given in Figure 2. In such a case, the problem becomes to estimate the location of the "correct" zero-crossing located around x = -5.6531 meters. Note that due to noise degradations, numerous zero-crossing points can be observed before the optimum fuzing point. As a result, we use an averaging filter to smooth the effects of the noise, and to insure that there is no zero-crossing before the optimum fuzing point. However, as a consequence, the averaging filter flattens out the response and introduces further error in the location of the estimated fuzing point. This problem can be minimized by using a non-linear median smoothing filter. The median filter preserves sharp and sustained changes in the response, and as such preserves the slope of the response better than the averaging filter does while smoothing some of the noise-like components out. However, the median filter usually does not smooth the noise-like components sufficiently. As a result, a good solution may be obtained with an algorithm which has a combination of first an averaging filter, and a second median filter, to insure a better estimation of the fuzing point. Mean and median filters, and the definition of the threshold needed to switch from one filter type to the other are discussed in further details in Section 3.

3. METHODOLOGY INVESTIGATED

3.1. INTRODUCTION TO THE MEAN AND THE MEDIAN FILTER

3.1. a. MEAN FILTER

The mean filter is an averaging process that acts as a smoothing filter as the technique outputs the average of the input points considered. Note that only causal outputs are used for the purpose of this study. A causal system is a nonpredictive system which means the output does not precede the input [2]. The causal mean function ($f_{(a)}$) expressed as a function of the input function ($f_{(i)}$) is given by:

$$f_{(a)}(n + L - 1) = \text{mean}(f_{(i)}(n \text{ to } n + L - 1)),$$

where n is the index of the data points and L is the length of the input sequence being considered by the filter. Figure 3 and 4 show an input and the result of smoothing the input by using a mean filter of length three ($L = 3$).

3.1. b. MEDIAN FILTER

The median filter is a non linear filter that outputs the median of the input points considered. Note that as a result of the non linearity structure, the slope of the input curve is preserved better than when the mean filter is used [3]. The median filter is used in a causal configuration, and the median function $f_{(m)}$ is expressed as a function of the input function $f_{(i)}$ given by:

$$f_{(m)}(n + L - 1) = \text{median}(f_{(i)}(n \text{ to } n + L - 1)).$$

Figure 3 and 4 show an input and the result of smoothing the input by using a median filter of length three.

3.2. MODEL

The model used here is the point-charge response of a short-circuit longitudinal sensor, where the electrostatic point-charge response $\frac{dEn}{dt}$ has been derived [1] to be:

$$\frac{dEn}{dt} = A\left(\frac{y^2-2x^2}{(x^2+y^2)^{5/2}}\right),$$

where $A = \frac{Qv_x}{4\pi\varepsilon_0}$ and Q is the charge (in Coulombs), v_x is the probe velocity (in the x-direction, in m/s), x is the distance between the probe and the point of closest approach, and y is the miss distance (orthogonal to x, in meters). Figure 1 is an illustration of the normalized point charge response with A = 1 and y = 8 meters.

The portion of the point charge response we concentrate on is the part before the explosion point is reached, or in this case, the part before the first zero crossing, as shown in Figure 5. The curve is composed only of very small frequency components, as shown by its Fourier transform in Figure 6. As a result, any low pass filter cancels the effects of a colored noise centered outside of the model bandwidth, illustrated in Figures 7 and 7.1. Thus, the most critical type of noise to consider is the white noise case as it covers the entire frequency spectrum Figure 2 shows the point charge response with additive white noise with a noise variance equal to 1/49.

3.3. DETECTION TECHNIQUE

3.3.a. DETECTION OF THE FUZING POINT - NOISE-FREE CASE

The fuzing point is located at the first zero-crossing of the point charge response, as illustrated in Figure 5. This first zero-crossing is computed by tracking the change of sign of the point charge response. The fuzing point value is found to be equal to -5.6531 meters in the x direction.

3.3.b. DETECTION OF THE FUZING POINT - NOISY CASE

When additive noise is present, the above simple detection procedure is no longer valid, as numerous zero-crossings occur due to the noise before the correct fuzing point value. The effects of the noise can be minimized by applying a simple low-pass averaging filter. This filter has the effect of suppressing early zero-crossings. However, it also has the drawback of attenuating the slope in the region where the true fuzing point occurs, and introduces further error in the estimation of the fuzing point. A non-linear filter, such as the median filter introduced in Section 3.1.b, can be used to preserve sudden sustained value changes in the data and filter some noise components. However, a median filter does not provide enough smoothing of noise-like components where the noisy point charge response is very small. As a result, a good compromise may be reached by using a combination of both mean and median filters to minimize the effects of the noise and better estimate the location of the fuzing point. The algorithm starts with a mean filter to smooth the effects of the noise down and to insure that no early zero-crossings occur. Once the filtered point charge response values fall below a predefined threshold, set by the user, the filtered point-charge response is insured not to cross the zero axis early. When the threshold value is reached, the detection procedure switches to the median filter. The median filter still smoothes the effects of the noise down and better preserves the slope of the point-charge response in the fuzing point neighborhood. Estimation of the fuzing point location is determined when the noisy response changes sign. Values for the length of the mean filter, the median filter, and the threshold value, are all set by the user. The resulting point charge response is defined as:

$$s_n(k) = s(k) + \sigma_w w(k),$$

where s(k) is the noise-free normalized point charge response, w(k) is an additive normal white noise with mean equal to zero and variance equal to one. The parameter σ_w is adjusted during the calculations to vary the power of the noise. The resulting Signal-to-Noise Ratio (SNR) for the noisy point charge response is defined in decibels as:

$$-10\log(\frac{\sigma_w^2}{s}),$$

where s is the point charge response power between -40 and 40 meters. Figures 8 through 9.1 show the noisy point charge response and the filtered noisy point charge response with the change of filters indicated by an asterisk (*) for three additive noise power levels.

The threshold equal to -0.20 and length of the filters equal to 15 are determined to insure a reliability of 99% . The reliability measure [4] is calculated in the following fashion:

$$R = 1 - \frac{n+0.7}{N},$$

where R is the reliability, n is the number of failures, and N is the number of trials. Figure 10 shows the normalized error measure defined as:

$$Er = \frac{|e_{est}-e_{th}|}{|e_{th}|},$$

where e_{est} is the estimated zero crossing location obtained using the proposed technique, and e_{th} = -5.6531 is the noise-free zero crossing location in meters, for 340 trials of the combination mean/median filtered noisy point charge response. In Figure 10 the noise variance is equal to 1/100, i.e. the SNR is equal to 8.2086 dB, and there is no error greater than one meter from the fuzing point which yields a reliability greater than 99%. The parameters for the filters are length (L) and the threshold (E) set to L = 15 and E = -0.2.

3.4. ROBUSTNESS OF MEAN/MEDIAN FILTER COMBINATION

The robustness of the mean/median filter combination is studied by varying the power of the white noise added to the model. One hundred (100) trials are computed for each white noise power. Figure 11 shows the mean and two standard deviations of the normalized error. The results show that the mean normalized error is maintained to within a meter for a noise variance less than 1/55, SNR less than 5.6122 dB. The standard deviations for two SNR realizations are near 0.2, which is the result of a trial at that noise variance having an early zero crossing. Further improvement for these two SNR realizations can be obtained by decreasing the value of the threshold to avoid an early zero crossing.

3.5. COLORED NOISE MODELS

Colored noise, formed as band limited Gaussian noise, can be used to simulate natural known noises in the target area. The MATLAB code implementation in the Appendix is menu driven and can be set to prompt the user for center frequency (fc) and a quality factor (Q):

$$Q = fc/(fu - fl),$$

where fu is the upper cutoff frequency and fl is the lower cutoff frequency. The program can also be set to accept the cutoff frequencies directly along with the sampling frequency. The sampling frequency is important to place the band of the noise in the proper place on the frequency spectrum. Figures 12 through 14.1 present examples of colored noise realizations and their spectra with different Q values.

4. RECOMMENDATIONS FOR FURTHER RESEARCH

This report investigated the applicability of time-domain techniques to estimate the fuzing location in the electrostatic detection problem. This preliminary study is restricted to the case of an ideal point charge response for a short circuit longitudinal sensor, and a miss distance fixed to eight meters. The main advantage of this analysis technique is its simplicity; a minimum of software would be needed for its implementation. The procedure uses a combination of a linear smoothing filter and a non-linear median filter to estimate the fuzing location in noisy conditions. The robustness of the technique to additive white noise distortions is also investigated. Initial results show that the time-domain analysis technique is promising; the error obtained in the estimation my be kept to within 10% of the true fuzing location for a Signal-to-Noise Ratio (SNR) greater than 5.41dB (i.e., for an additive noise power less than 0.02) in 86% of the distortion levels investigated. For two of the SNR realizations investigated the error goes up to a maximum of 27% of the true value. Further improvements can be obtained by refining the choices for the threshold, and the filter lengths.

Several points, which have not been considered in this preliminary study, need to be addressed if the study is to be taken any further. One needs to investigate the robustness of the procedure to specific additive colored noise distortions. Note that due to the low frequency contents of the ideal point-charge response, only colored noise which have bandwidths that overlap the bandwidths of the point charge response need to be investigated. Furthermore, we have restricted our study to a time-domain analysis. Improvements may potentially be obtained by investigating frequency techniques and correlation procedures, and further work is needed to compare their performances. In addition, the results presented in this preliminary study are restricted to the case of a point charge response for a longitudinal sensor, and for a fixed miss distance. Typical signatures are more complex [1], and one needs to assess the applicability of any technique investigated to real-time signatures.

Figure 1 Normalized point charge response with the miss distance equal to eight meters.

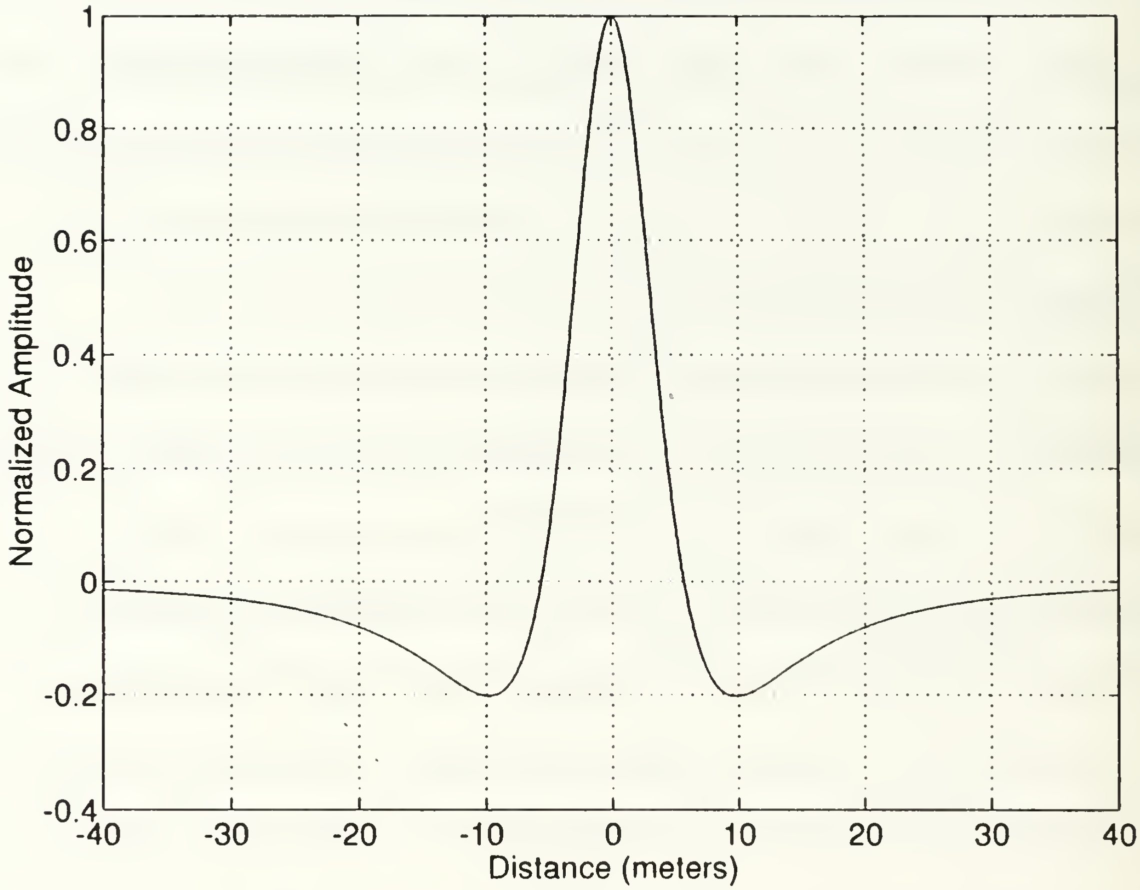


Figure 2 Point charge response with additive white noise, SNR = 5.11 dB

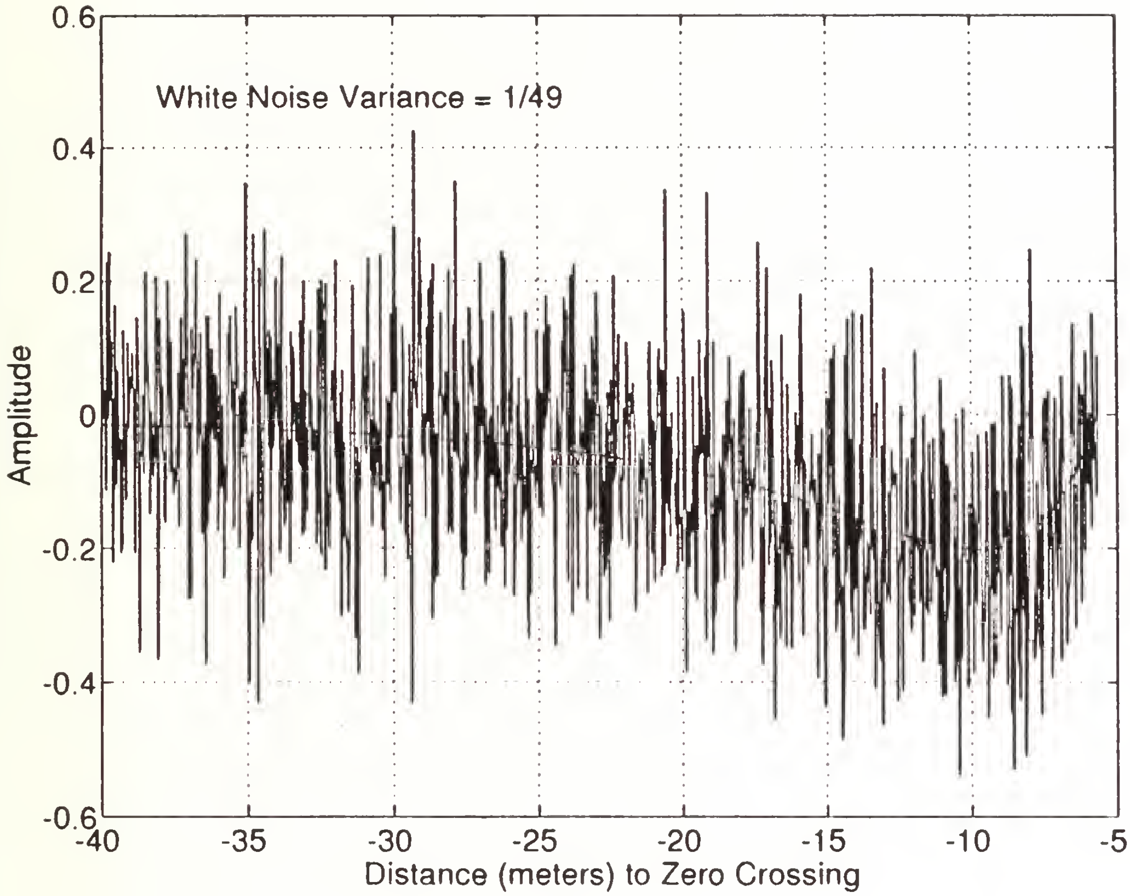


Figure 3 Input/output relationships for the mean and median filter of length three (L = 3). The input data sequence length is 12 (N = 12). The output stays equal to zero until the filter is completely initialized.

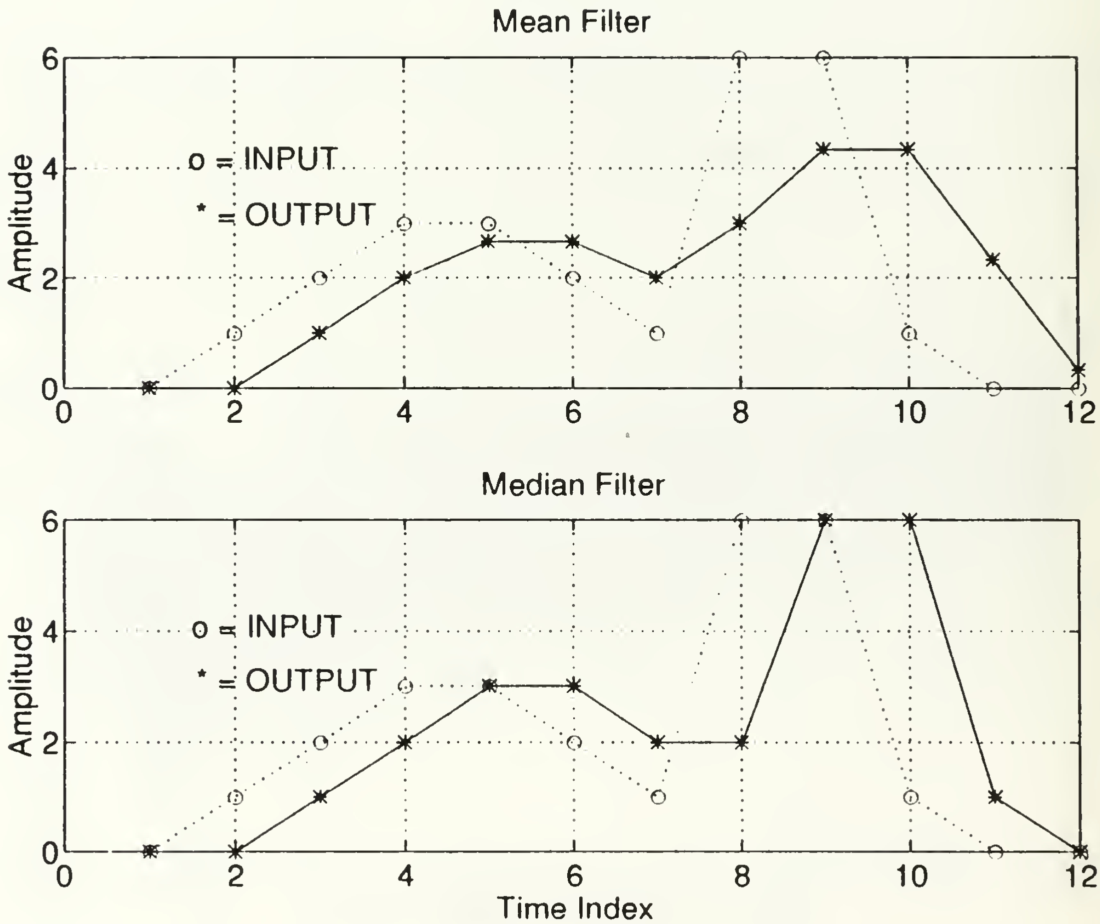


Figure 4 Input/output relationships for the mean and median filter of length three (L = 3). The input data sequence length is 112 (N = 112). The output stays equal to zero until the filter is completely initialized.

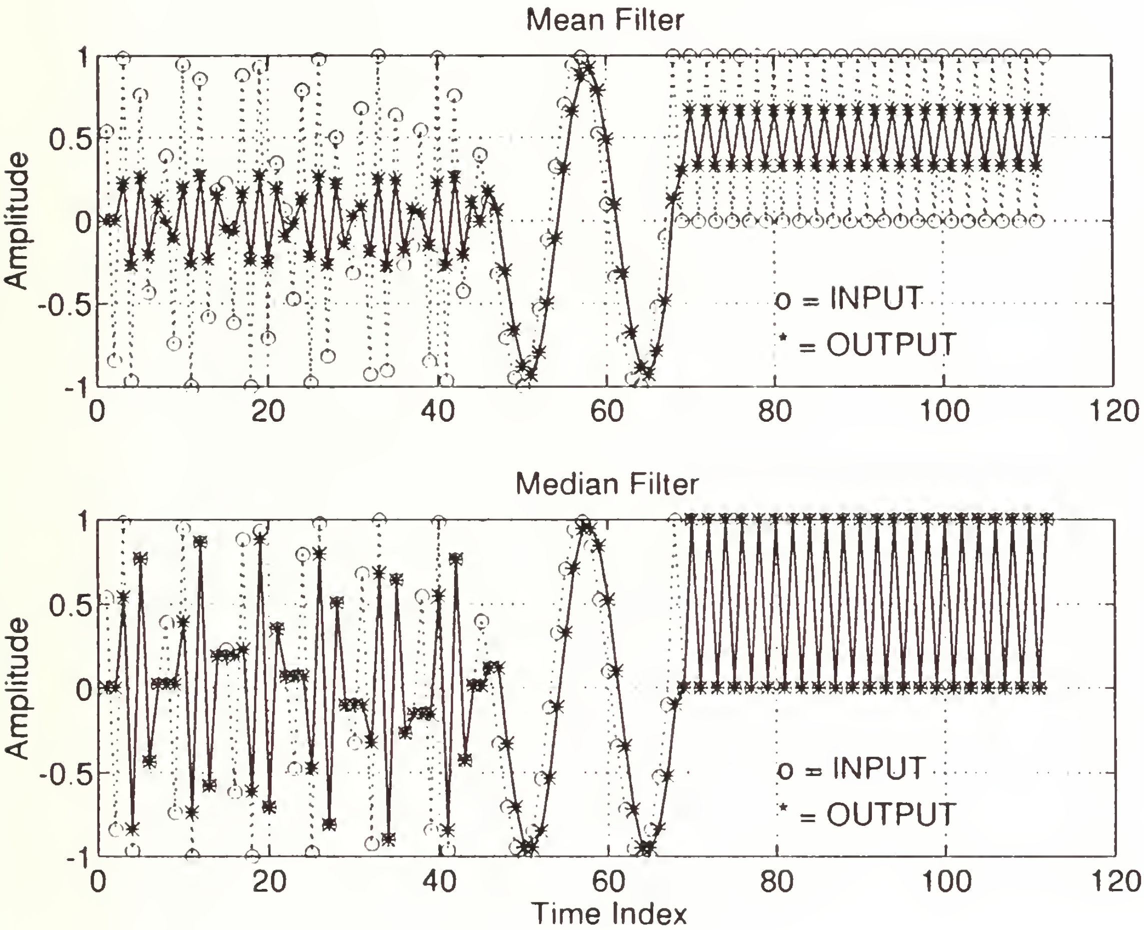


Figure 5 Critical portion of normalized point charge response, before the explosion point/first zero crossing. The miss distance is equal to eight meters.

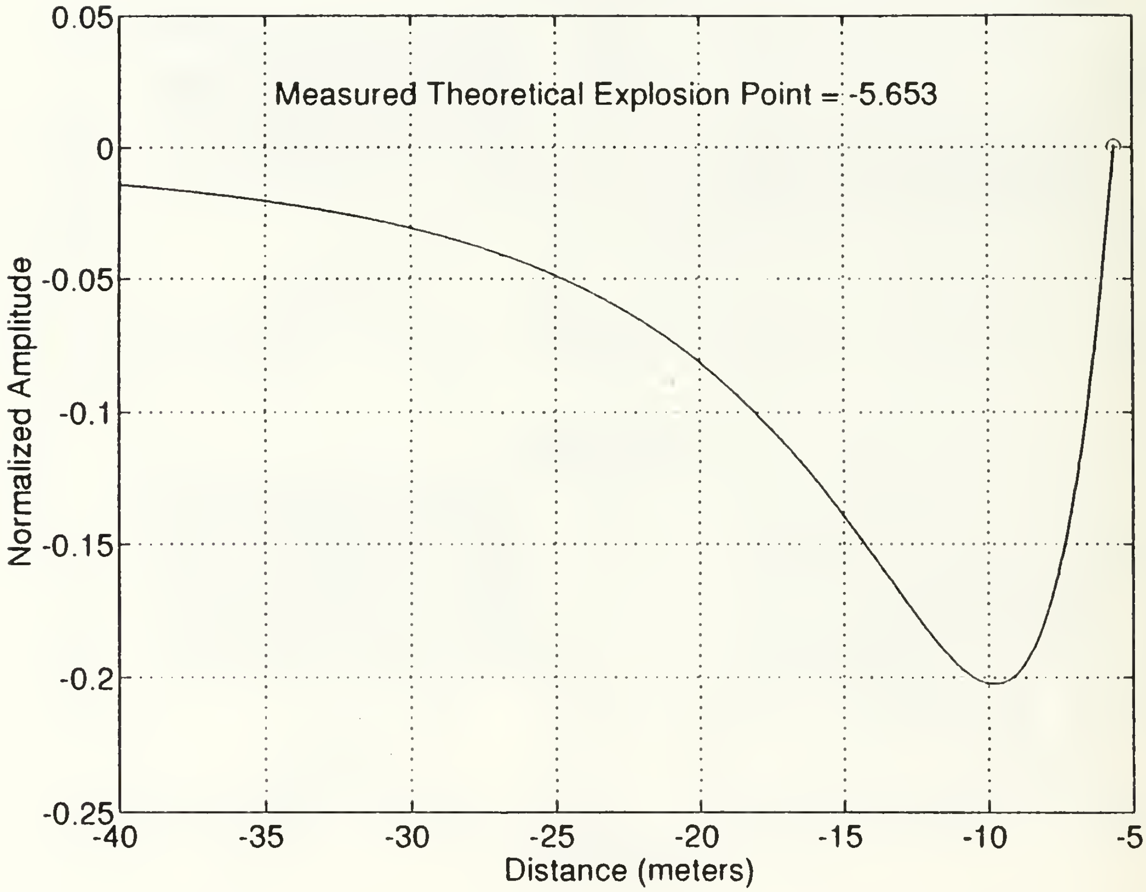


Figure 6 DFT of the point charge response.

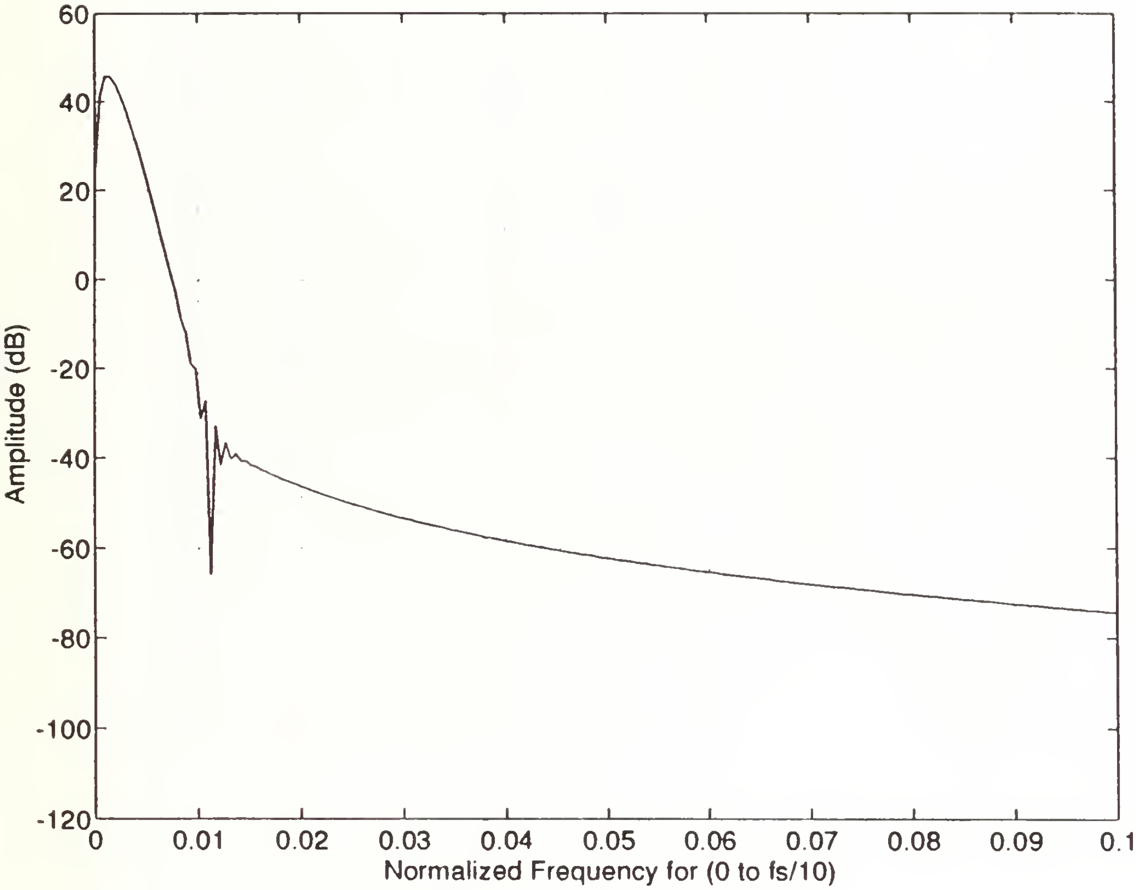


Figure 7 Point charge response with additive colored noise, SNR = -0.76 dB.

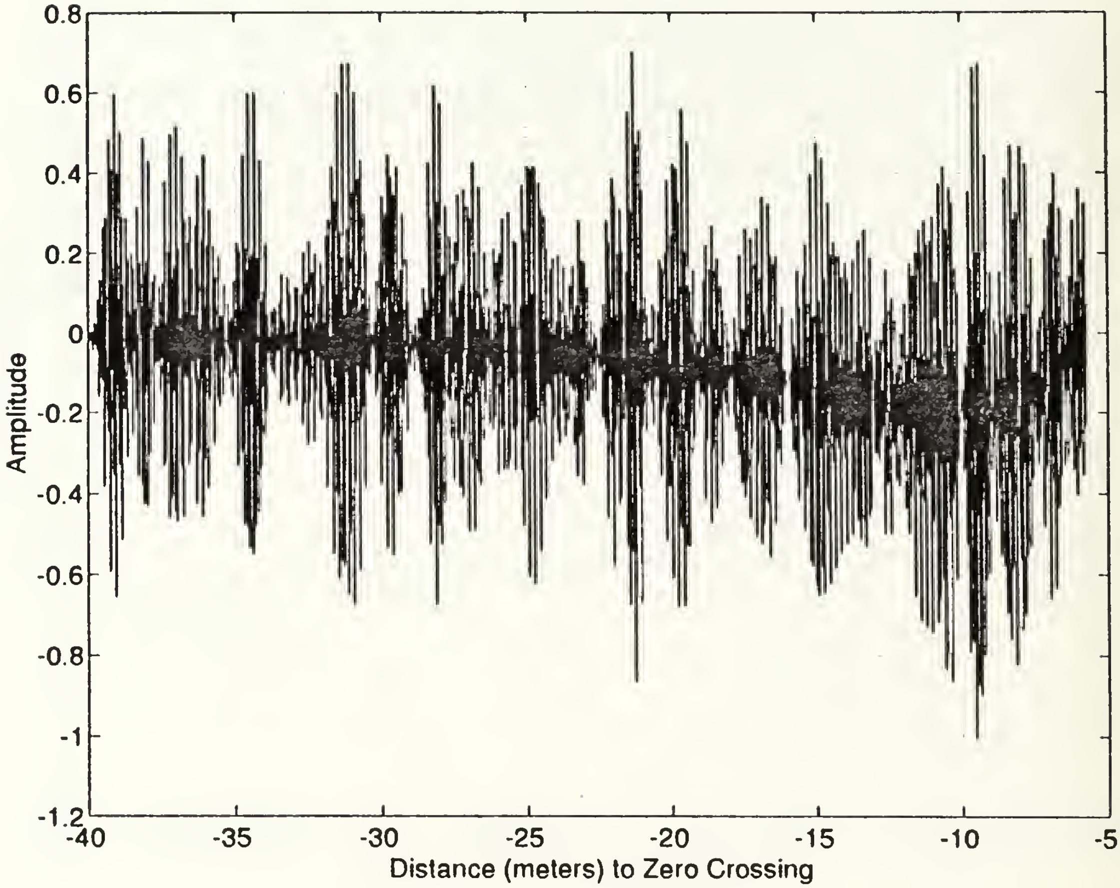


Figure 7.1 Mean filtered point charge response with colored noise. The noisy point charge response is presented in Figure 7.

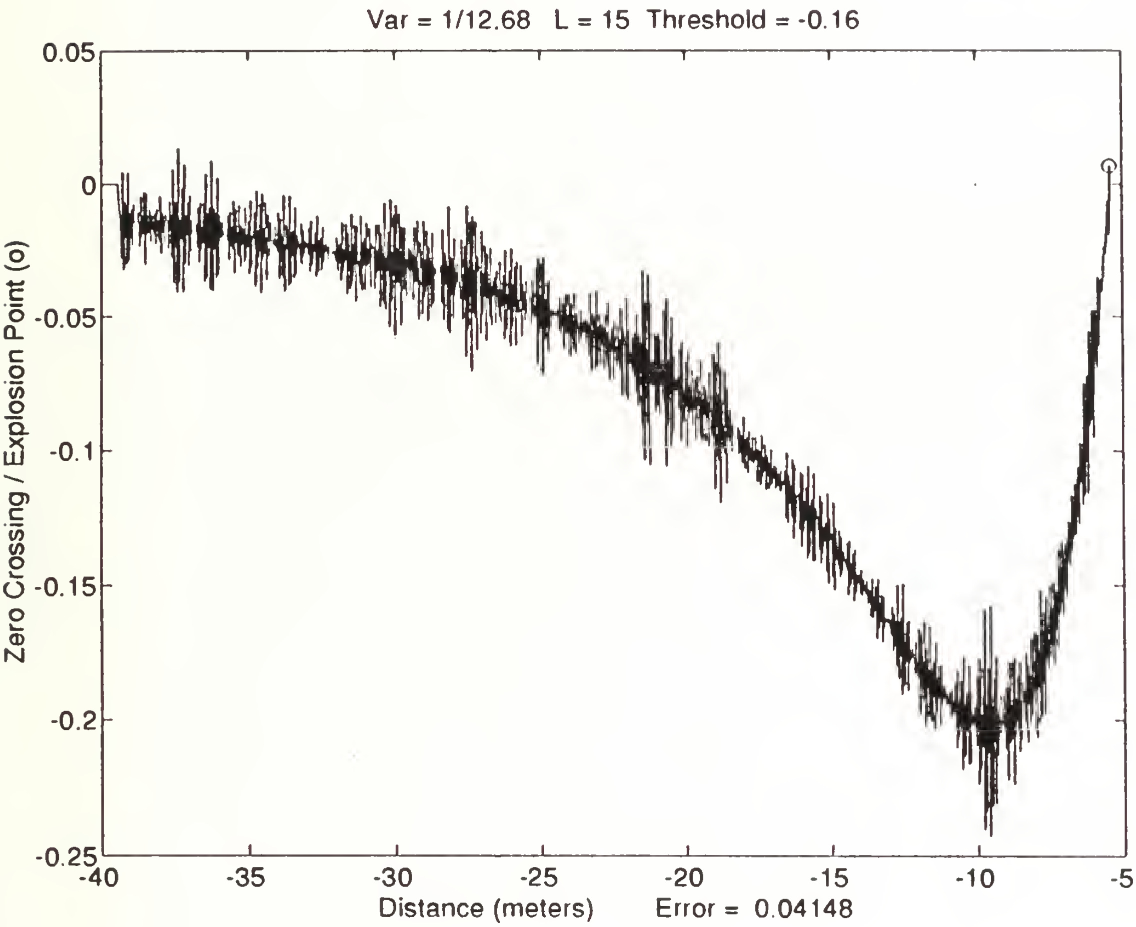


Figure 8 Point charge response with additive white noise, SNR = 8.37 dB.

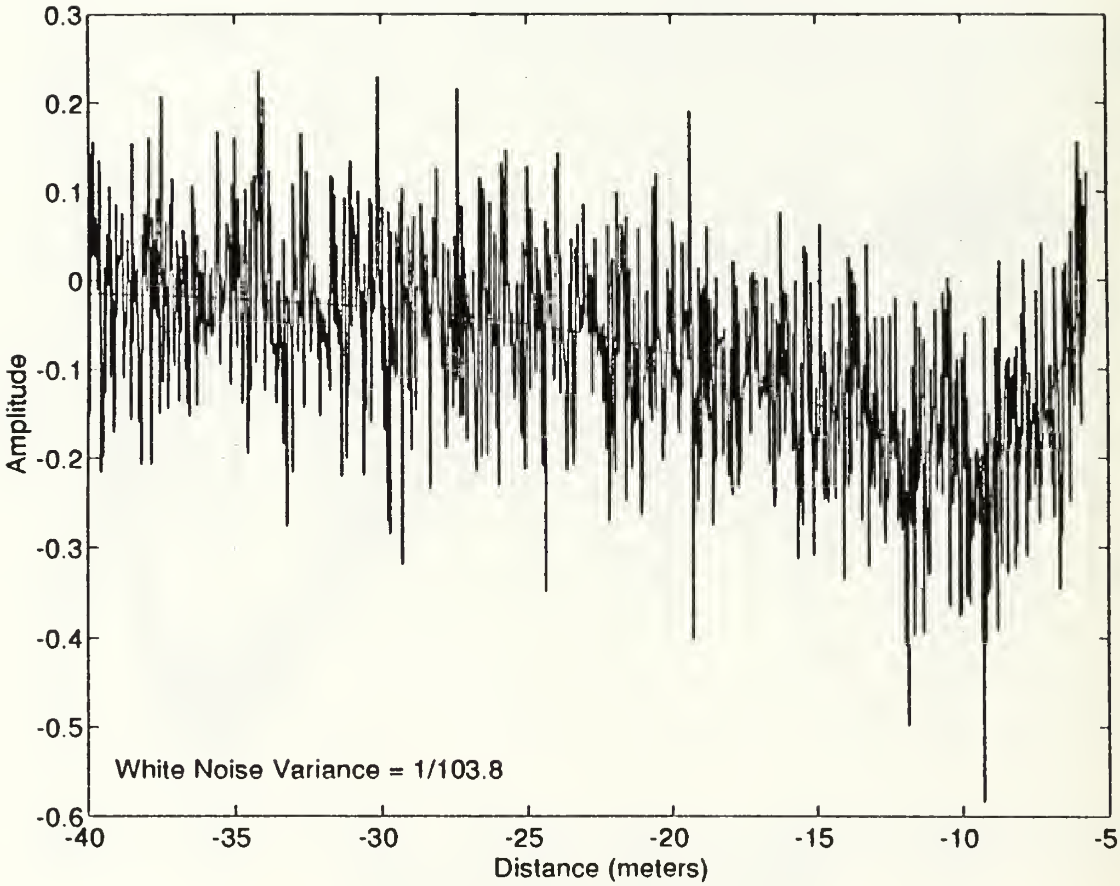


Figure 8.1 Combination mean/median filtered noisy point charge response. The noisy point charge response is presented in Figure 8. The threshold point is represented by (*), and the zero crossing/fuzing point is represented by (o)

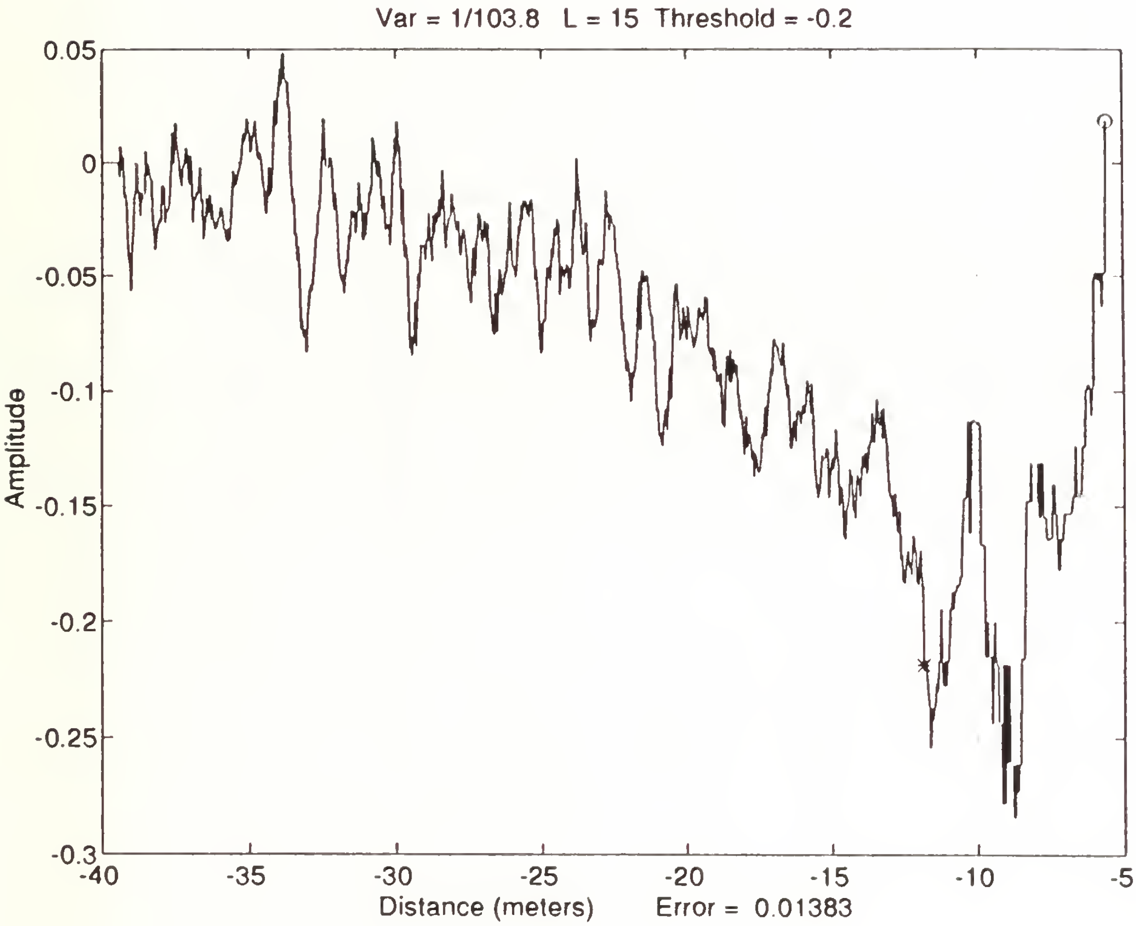


Figure 9 Point charge response with additive white noise, SNR = 4.86 dB.

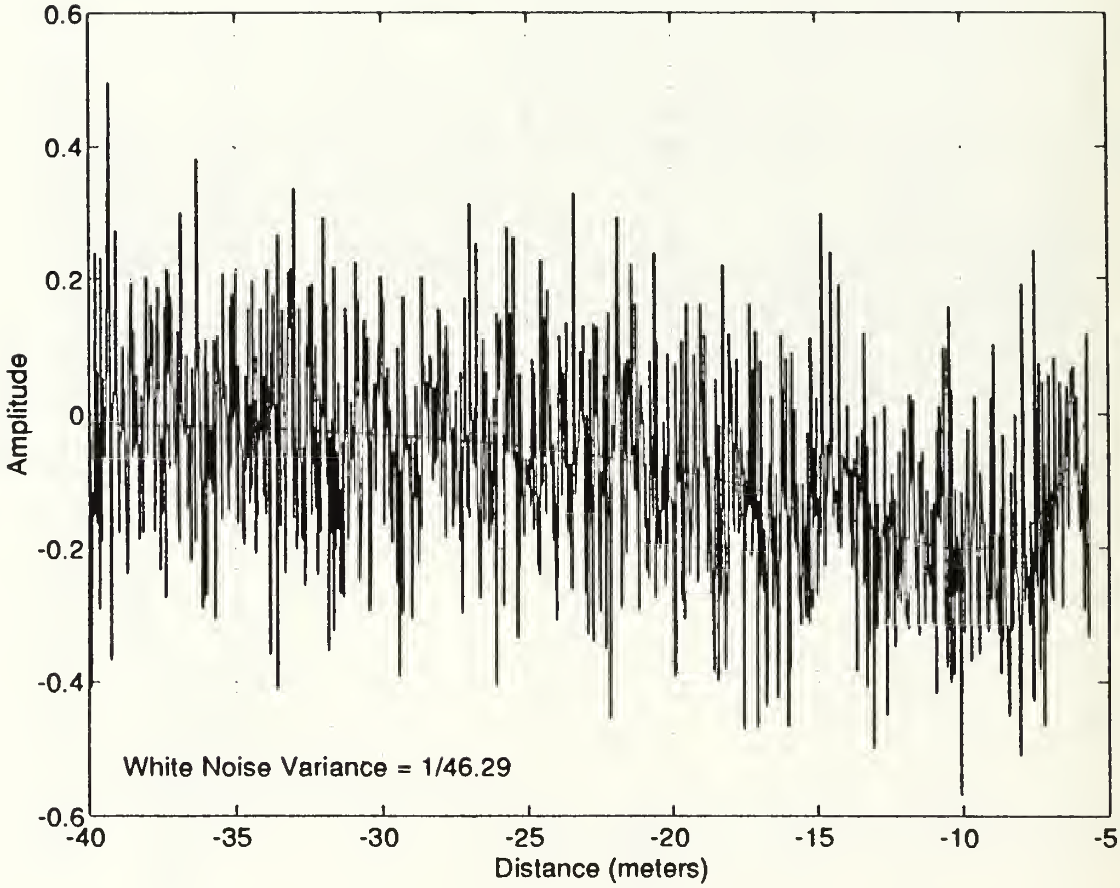


Figure 9.1 Combination mean/median filtered noisy point charge response. The noisy point charge response is presented in Figure 9. The threshold point is represented by (*), and the zero crossing/fuzing point is represented by (o).

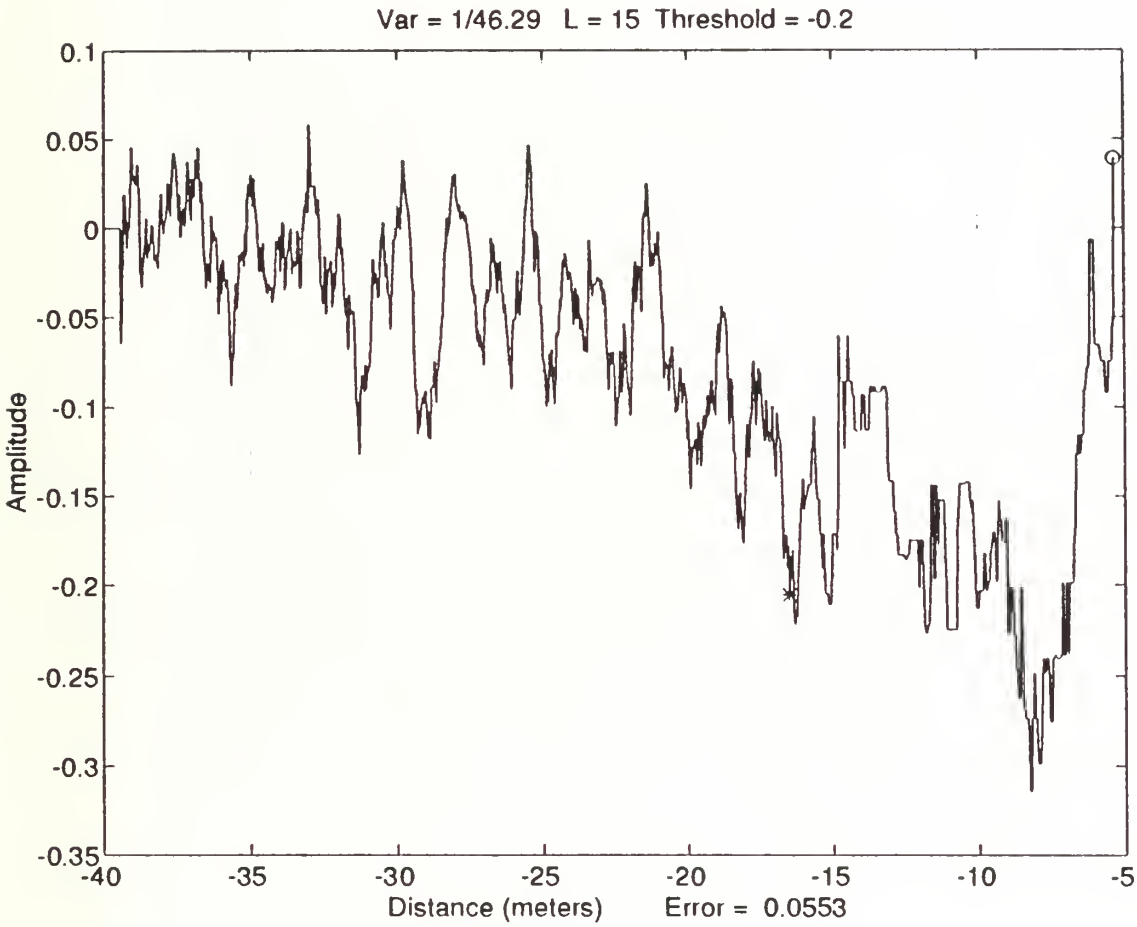


Figure 10 Reliability test of the combination mean/median filter.

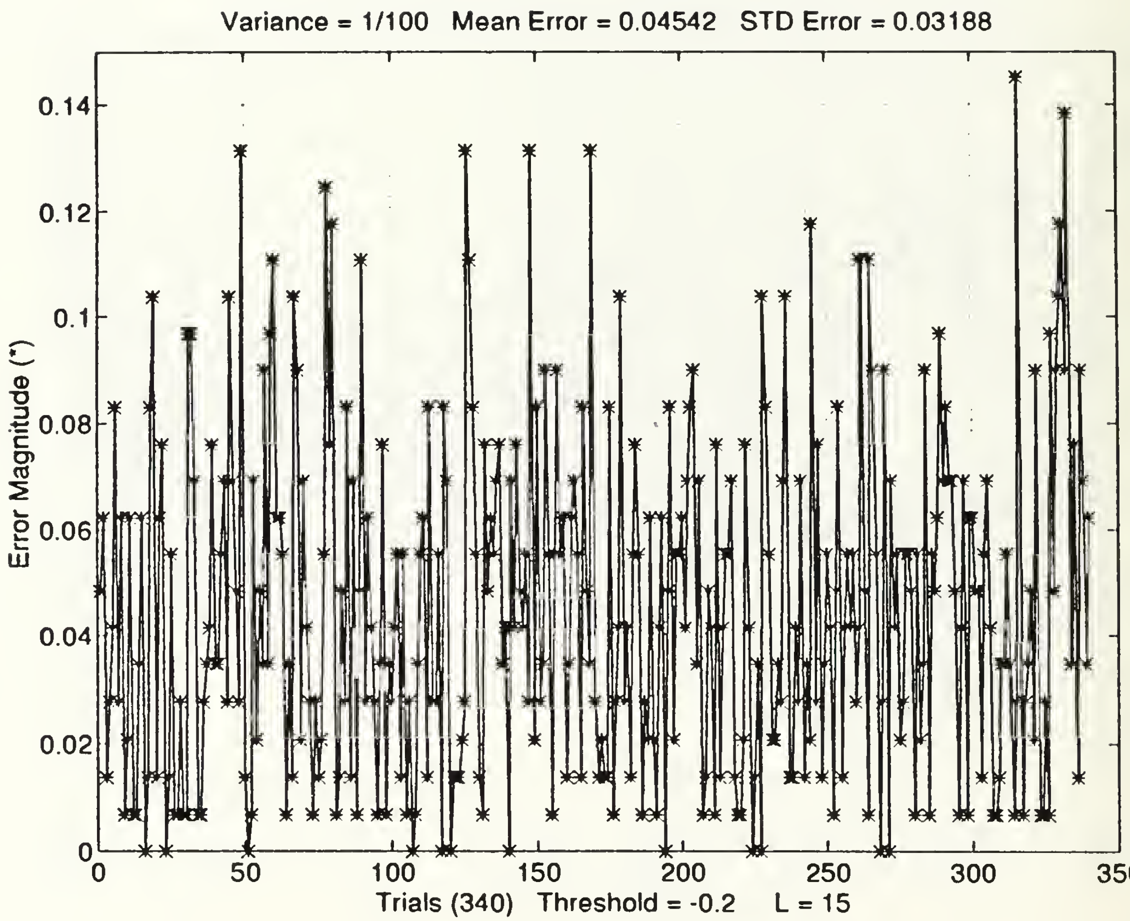


Figure 11 Robustness of the mean/median filter combination. Noise variance between 0.01 (SNR = 8.2086 dB) and 0.02 (SNR = 5.1983 dB). The mean error is represented by (*), one standard deviation from the mean error is represented by (+), 100 trials per SNR realization.

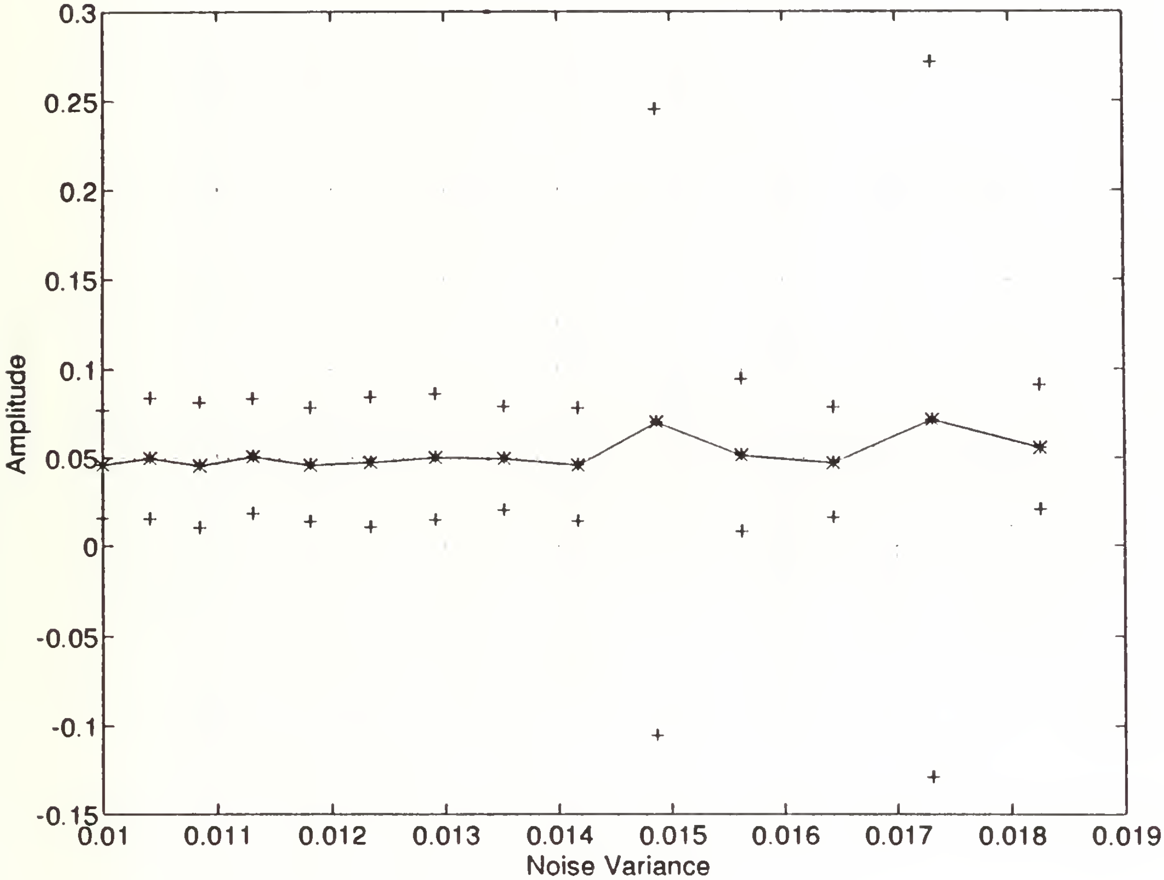


Figure 12 Band limited Gaussian noise (colored noise).

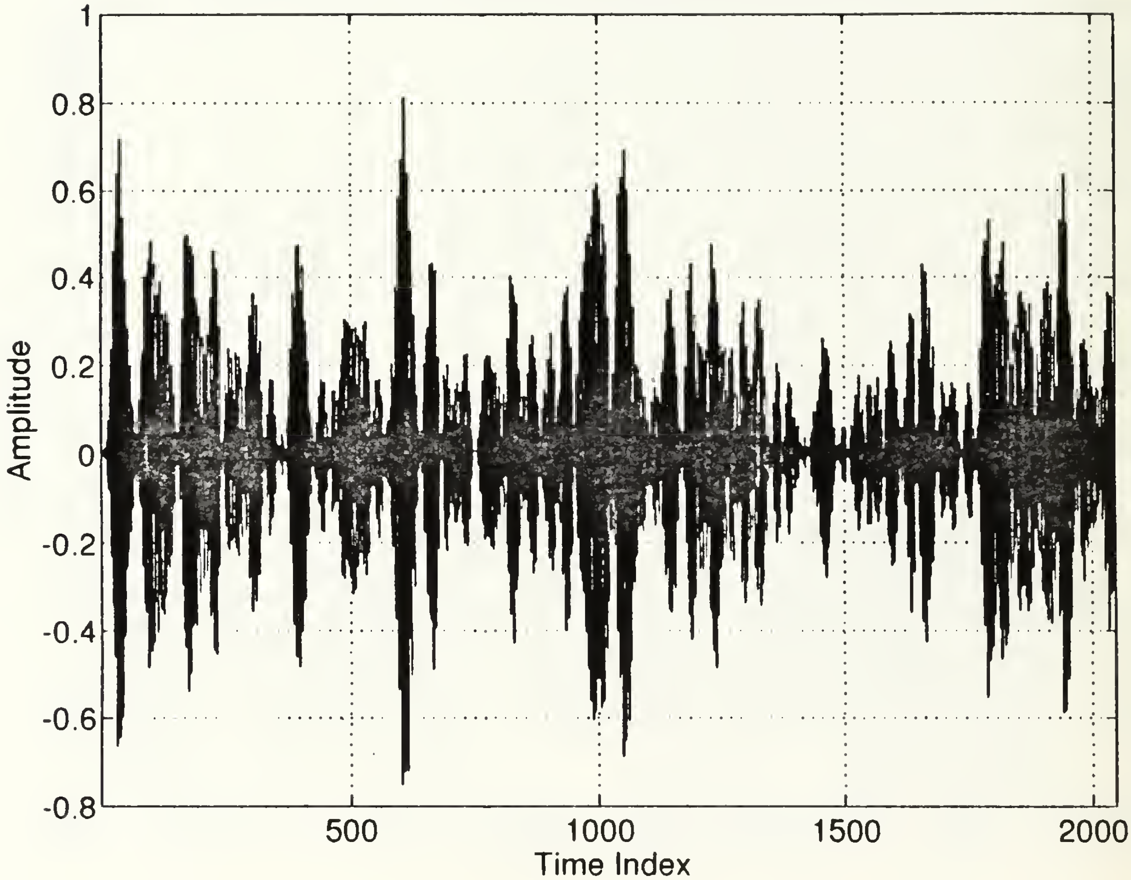


Figure 12.1 Frequency spectrum for the colored noise presented in Figure 12 Fc is the center frequency in Hertz, fs is the sampling frequency in Hertz, Q is the quality factor, and N is the order of the FIR filter.

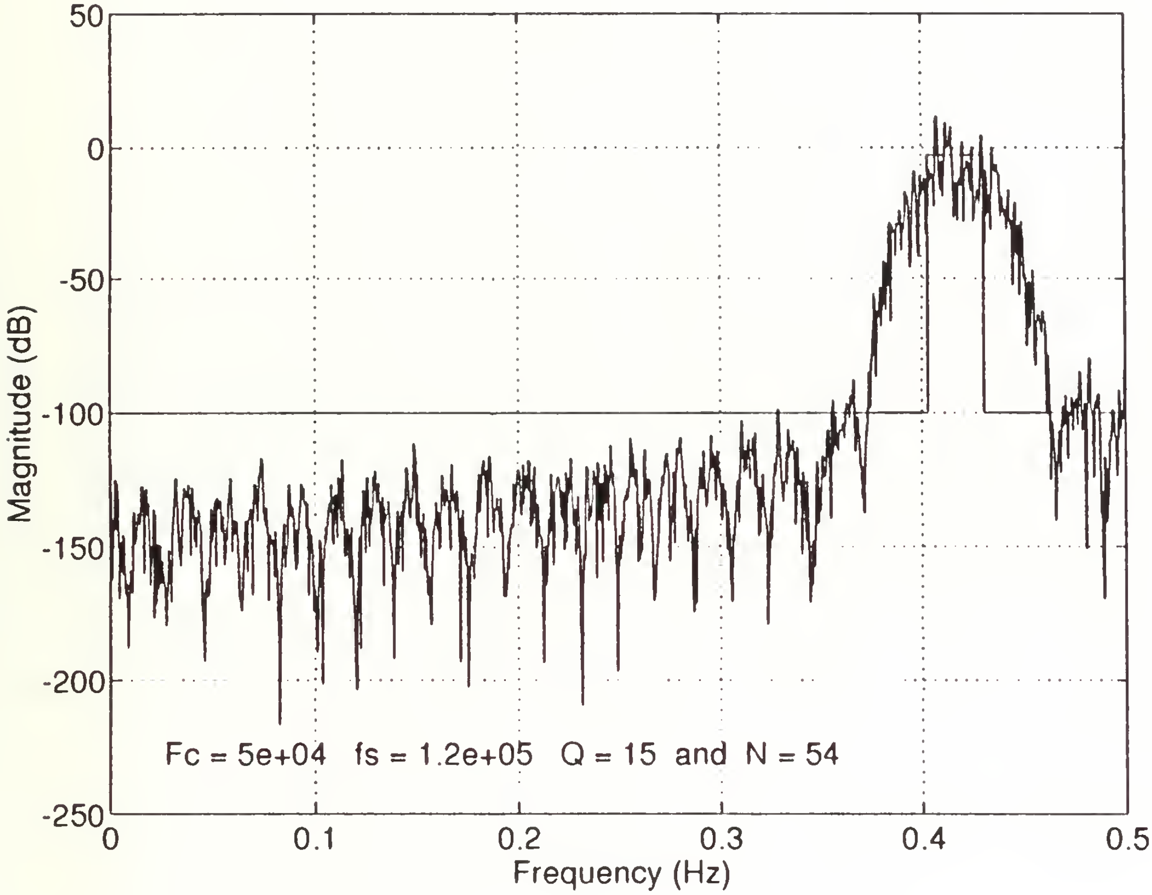


Figure 13 Band limited Gaussian noise (colored noise).

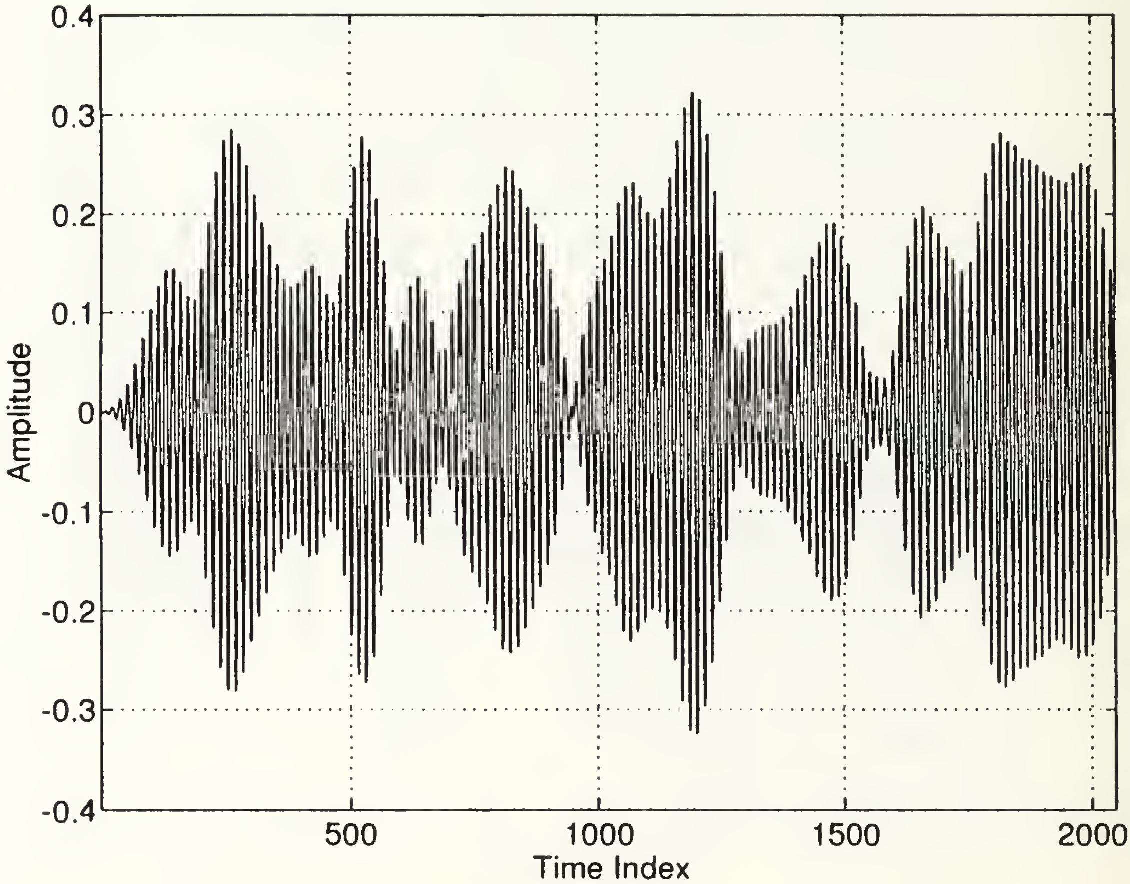


Figure 13.1 Frequency spectrum of the colored noise presented in Figure 13. Fc is the center frequency in Hertz, fs is the sampling frequency in Hertz, Q is the quality factor, and N is the order of the FIR filter.

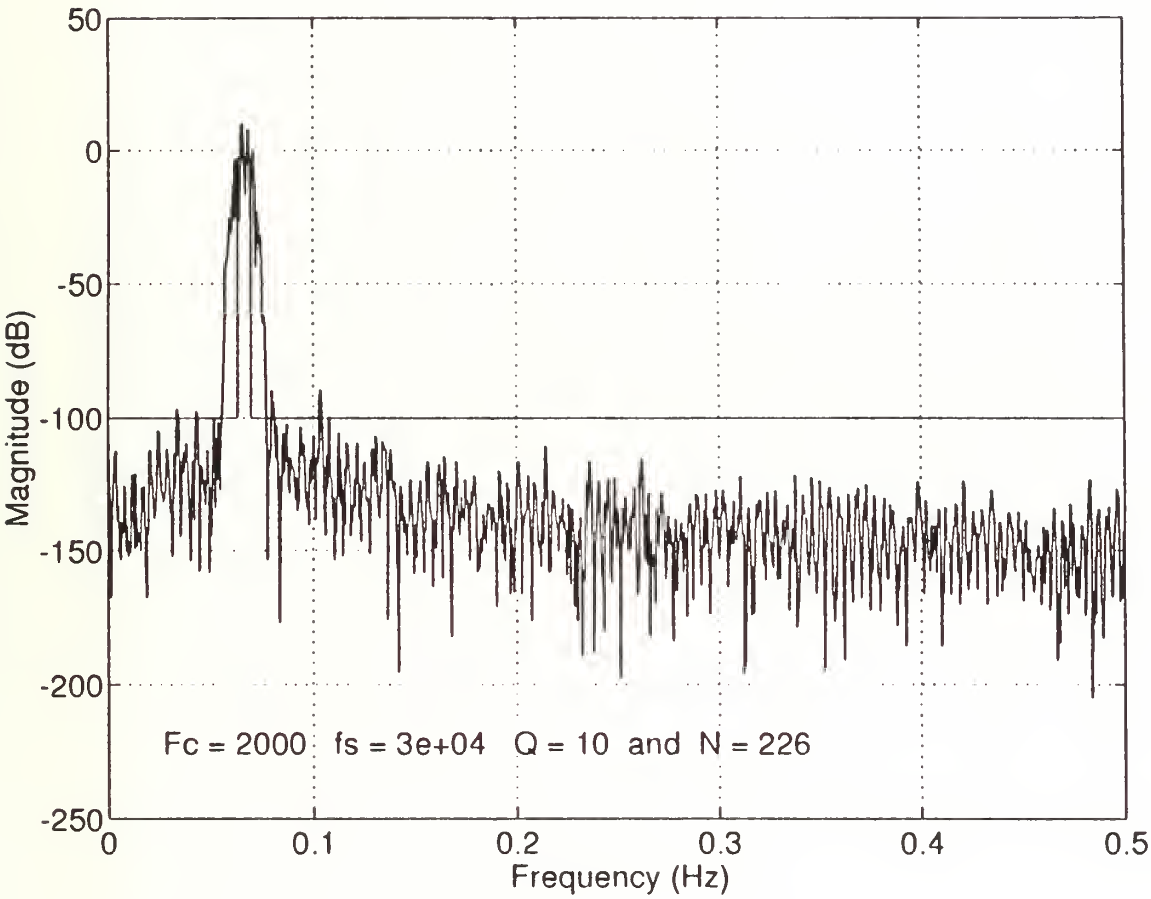


Figure 14 Band limited Gaussian noise (colored noise).

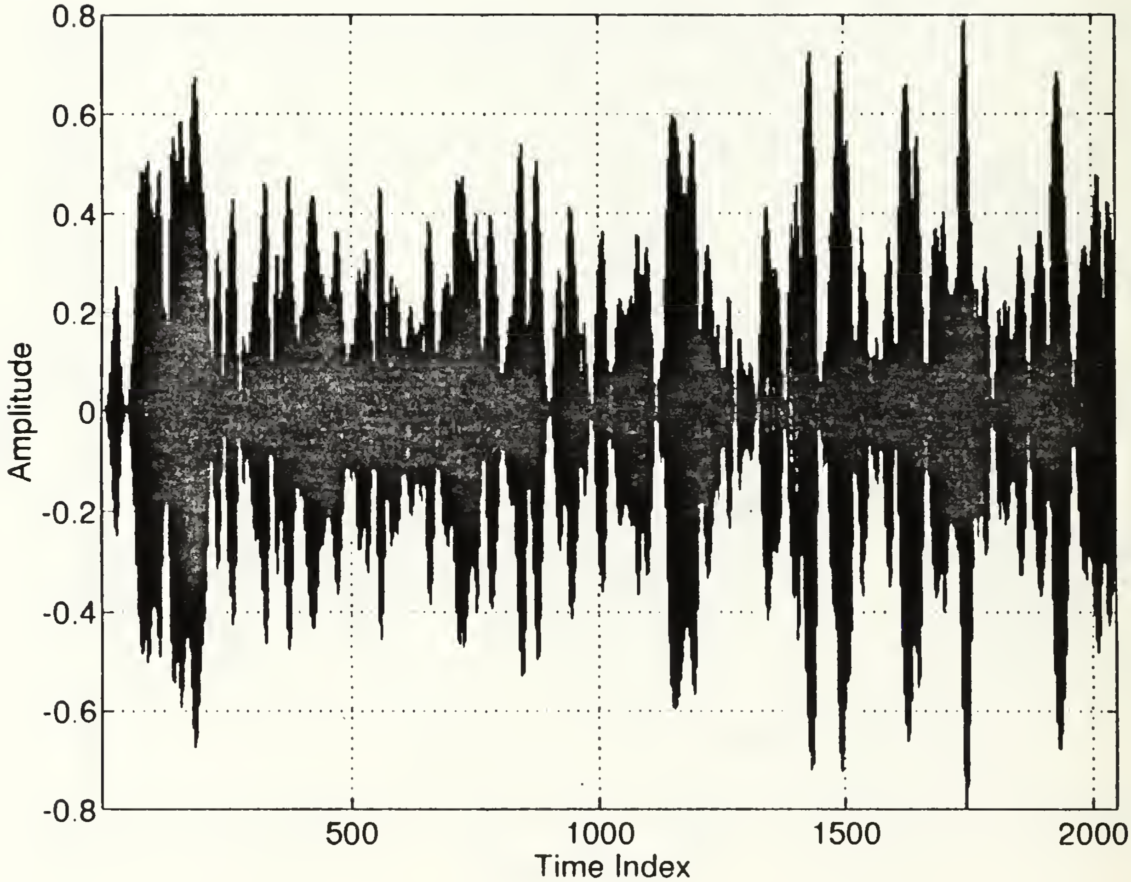
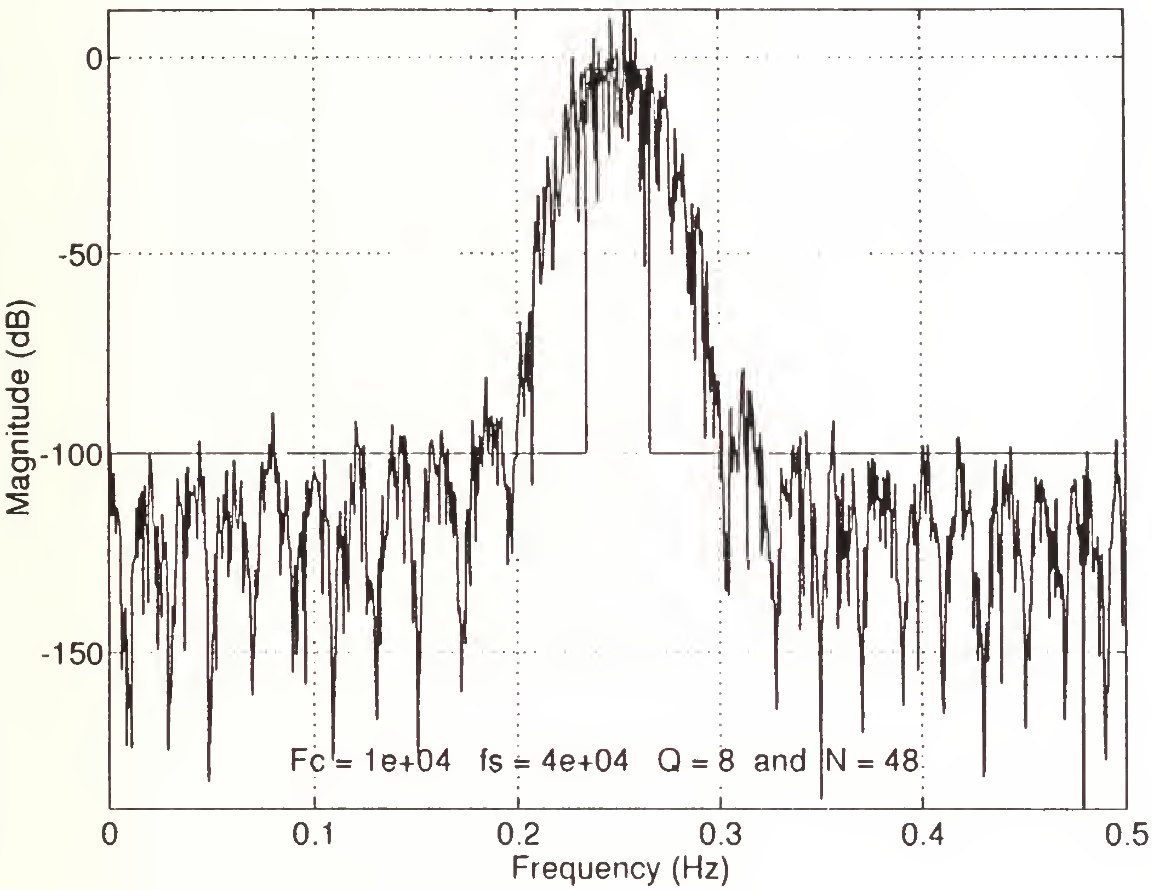


Figure 14.1 Frequency spectrum of the colored noise presented in Figure 14. Fc is the center frequency in Hertz, fs is the sampling frequency in Hertz, Q is the quality factor, and N is the order of the FIR filter.



REFERENCES

1. Hull, D. H., Internal Report, U. S. Army Research Laboratory, Aldelphi, Maryland, September 1993.

2. Strum, R. D., and Kirk, D. E., *Discrete Systems and Digital Signal Processing*, Addison Wesley, 1989.

3. Rabiner, L. R., Sambur, M. R., and Schmidt, C. E., "Applications of a Nonlinear Smoothing Algorithm to Speech Processing," IEEE Transactions on Acoustics, Speech, and Signal Processing, VOL. ASSP-23, NO. 6, pp. 552-557, December 1975.

4. Fassnact F., *Principles of Systems Engineering*, ECE 4010 Class Notes, U. S. Naval Postgraduate School, Monterey, California, Spring 1993.

Appendix MATLAB code implementation

```
% GNF.m  John K. Dewey
% Generates Colored Noise,formed as, Band Limited Gaussian Noise
% Uses function finddbf.m to measure Center Frequency and
%  Q values.
% Matlab toolbox functions used: FIR1.m, FREQZ.m, SIZE.m

clear % Clears all previous variables

% Input Arguments
Fc = input('Enter the center frequency = '); G0 = num2str(Fc);
Q = input('Enter the value for Q = '); G1 = num2str(Q);
fs = input('Enter the sampling freqecy fs = '); G2 = num2str(fs);

% Translate Q to cutoff frequencies
Fl = Fc - Fc/Q/2;
Fu = Fc + Fc/Q/2;

% Input can be set to accept the cut off frequencies directly
%   Fc =
%   Fl =
%   Fu =
%  Q = Fc/(Fu-Fl);

% Specs
yspecs = [-100 -100 -3 -3 -100 -100];
xspecs = [0 Fl Fl Fu Fu fs/2];

% Normalize Specs
xnspecs = xspecs ./fs;

% Set warning to eliminate aliasing
if fs/2 < Fu + Fc/Q/2
Warn = ['                    ';'Warning Aliasing Warning'];
disp(Warn)
break
end

% Find the order of the filter
N = 28; % The first guess
Qz = 1; % The minimum Q

while Qz < Q
F = [2*Fl/fs 2*Fu/fs];
[B] = fir1(N,F);
[H] = freqz(B,1,2048);
magz = 20*log10(abs(H));
xax = 0:(fs/2)/(length(magz)-1):fs/2;
[WCz,Qz] = finddbf(magz,xax);
N = N+2;
end
N = N-2; G3 = num2str(N);
```

```
% Generate White Gaussian Noise
t = 1:2048;
wn = randn(size(t));

% Color White Noise
Hf = filter(B,1,wn);
S = spectrum(Hf,2048);
[n,m] = size(S);
y = 20*log10(S(2:n));
x = (0:fs/2/(n-2):fs/2);
xn = x ./fs;

% Display the Frequency Spectrum of the Colored Noise
plot(xnspecs,yspecs,xn,y)
title('Spectrum of the Colored Noise')
gtext(['Fc = ',G0,'   fs = ',G2,'   Q = ',G1,'  and  N = ',G3])
xlabel('Frequency (Hz)'),ylabel('Magnitude (dB)'),grid
figure

% Display the Colored Noise
plot(1:length(Hf),Hf)
title('Colored Noise')
xlabel('Index')
ylabel('Magnitude')
grid

% Save the Colored Noise for future use
%save cn Hf
```

```
% FINDDBF.m, Fall 1993, John K. Dewey
% A Function that measures the Center Frequency and Q values
% [WC,Q] = finddbf(mag,f)
% input magnitude and frequency

function[WC,Q] = finddbf(mag,f);

% Find the Center Frequency Point
[pk,Ic] = max(mag);

% Find the -3dB cut off frequencies
A = abs(mag - pk + 3);
[xl,ql] = min(A(1:Ic));
[xll,qr] = min(A(Ic:length(A)));

% Find the Center Frequency
WC = f(Ic);

% Compute Q
Q = f(Ic)/((f(qr+Ic)-f(ql)));
```

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