GEORGIA INSTITUTE OF TECHNOLOGY — OFFICE OF CONTRACT ADMINISTRATION

PROJECT ADMINISTRATION DATA SHEET

[X] ORIGINAL [ ] REVISION NO. ______

Project No. E-21-J12 R5962-AB2 GTRC/~~XXX~~ DATE 4 / 10 / 86

Project Director: Dr. D.T. Paris School/~~Lab~~ EE

Sponsor: Naval Coastal Systems Center Panama City, Florida 32407

Type Agreement: Delivery Order No. 12 Under IQC N61331-85-D-0025 (OCA File #93)

Award Period: From 3/19/86 To 8/19/86 (Performance) 8/19/86 (Reports)

Sponsor Amount:

	This Change	Total to Date
Estimated:	$	$ 41,058.00
Funded:	$ 41,058.00	$ 41,058.00

Cost Sharing Amount: $ ______ Cost Sharing No: ______

Title: Low Probability of Intercept Signal Processing

ADMINISTRATIVE DATA OCA Contact R. Dennis Farmer X4820

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Defense Priority Rating: DO-C9

Military Security Classification: UNCLASSIFIED
(or) Company/Industrial Proprietary: N/A

RESTRICTIONS

See Attached GOVERNMENT Supplemental Information Sheet for Additional Requirements.

Travel: Foreign travel must have prior approval — Contact OCA in each case. Domestic travel requires sponsor approval where total will exceed greater of $500 or 125% of approved proposal budget category.

Equipment: Title vests with Georgia Tech if less than $5,000.00 with prior Contracting Officer approval.

COMMENTS:

(Subcontracted to Tuskegee University)

Contact OCA Subcontracts to initiate Subcontracting Agreement

RECEIVED APR 1986 SUPPORT SERVICES OCA

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Project Director	Procurement/GTRI Supply Services	GTRC
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Research Property Management	Reports Coordinator (OCA)	Project File
Accounting	Research Communications (2)	Other Jones/Legal

FORM OCA 65:285

EORGIA INSTITUTE OF TECHNOLOGY — OFFICE OF CONTRACT ADMINISTRATION

SPONSORED PROJECT TERMINATION/CLOSEOUT SHEET

Date 1/7/87

oject No. E-21-J12

School/~~Lab~~ EE

cludes Subproject No.(s) N/A

oject Director(s) D. T. Paris

GTRC /~~GIT~~

onsor Naval Coastal System Center Panama City, Florida 32407

tle Low Probability of Intercept Signal Processing

fective Completion Date: 8/19/86 (Performance) ______ (Reports)

ant/Contract Closeout Actions Remaining:

- [ ] None
- [x] Final Invoice or Final Fiscal Report
- [x] Closing Documents
- [x] Final Report of Inventions Questionnaire sent to P. I.
- [x] Govt. Property Inventory & Related Certificate
- [ ] Classified Material Certificate
- [ ] Other ______

ontinues Project No. ______ Continued by Project No. ______

OPIES TO:

oject Director
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Project File
Other Ina Lashley
Angela Jones
Russ Embry

ORM OCA 69.285

E-21-512

April 15, 1986

STATUS REPORT FOR CONTRACT RFP # N61331-86-Q-2011

A task/assignment list has been developed for the covert signal processing contract. The direction will be orientated towards covert sonar systems. The tasks are outlined as follows:

i)Develop simulation models for the channel and sea-state environment to enable transmission and reception of a sonar signal. This model will include reverberation, sea-state noise, and multipath reflection (both surface and bottom).

ii)For the above model, design a signal set using vector quantization which has spectral properties similar to the sea-state environment.

iii)Using computer simulation, determine the effectiveness of vector quantization for covert sonars. The major issues will be:

a)Signal strength required for good reception of returning sonar signal,
b)Robustness of vector quantizer signal set to changing environments,
c)Time delay and computational load associated with this system.

The tasks described above would allow for future tests of this system in a sonar test bed (involving possible contract work for next year). These tests would give a measure on the effectiveness of the technique the accuracy of the model.

Up to date, the following areas have been worked on:

i)Software development of vector quantization design algorithm towards an environmentally trained system,

ii)Software development of the channel model (reverberation and multipath).

NCSC has agreed to supply the following items to me by May 1.

i)Noise probability distribution models to be used in this work,

ii)Transducer frequency response data.

The scheduled arrival date of the MicroVaxII is May 9.

May 15, 1986

STATUS REPORT FOR CONTRACT RFP # N61331-86-Q-2011

Here is an update on the tasks that have been worked on for period 4/15/86 through 5/15/86.

i)Algorithm and Software Program Development for the Vector Quantization Signal Set Design, Technique Enables VQ Codebook Design for any Environment
Present Status - 80 % Complete

ii)Channel Modeling and Software Program Development, Noise, Reverberation, Multipath, Modeling for Software Program Development
Present Status - 20% Complete

My efforts for the next month will be towards the further development of task ii) shown above.

June 15, 1986

STATUS REPORT FOR CONTRACT RFP # N61331-86-Q-2011

The following tasks have been worked on during the period 5/15/86 through 6/15/86.

i)Algorithm and Software Program Development for the Vector Quantization Signal Set Design, Technique Enables VQ Codebook Design for any Environment
Present Status - 90% Complete

ii)Channel Modeling and Software Program Development, Noise, Reverberation, Multipath, Modeling for Software Program Development
Present Status - 40% Complete

iii)System Integration and Software Integration, Covert Sonar System Software Development
Present Status - 30% Complete

Efforts for the next month will be towards the further development of tasks ii) and iii) shown above.

July 15, 1986

STATUS REPORT FOR CONTRACT RFP # N61331-86-Q-2011

The following tasks have been worked on during the period 6/15/86 through 7/15/86.

i)Algorithm and Software Program Development for the Vector Quantization Signal Set Design, Technique Enables VQ Codebook Design for any Environment
Present Status -100% Complete

ii)Channel Modeling and Software Program Development, Noise, Reverberation, Multipath, Modeling for Software Program Development
Present Status - 70% Complete

iii)System Integration and Software Integration, Covert Sonar System Software Development
Present Status - 40% Complete

Efforts for the next month will be towards the further development of tasks ii) and iii) shown above.

E-21-312

Tuskegee University

Founded by Booker T. Washington

School of
Engineering and Architecture

November 19, 1986

Ms. Candy Robertson
Naval Coastal Systems Center
Code 04
Panama City, Florida 32401

Ms. Robertson:

Here is the final report for research contract RFP # N61331 entitled "Covert Signal Processing Using Vector Quantization". I have also included with this letter a magnetic tape consist- of the software programs developed for this research. The tape is readable using the "tar" command on a UNIX based system. Please feel free to contact me if any questions arise concerning the programs or reading the tape.

Per our conversation the week of 11/10/86, I hope that you can circulate this report to the appropriate people. I also hope that this work can be extended towards a full year contract.

I thoroughly enjoyed the research effort between our two organizations. Thank you for your continued support during the tenure of this research effort.

Sincerely,

Dr. John Foster

12/18/86 - spoke to Gary Kekelis at NCSC. He has received software.
Cindy Meyer

Tuskegee, Alabama 36088

E-21-512

FINAL REPORT FOR RFP # N61331-86-Q-2011

Title: Covert Signal Processing Using Vector Quantization

Investigator: John Foster

Organization: Department of Electrical Engineering,
Tuskegee University, Tuskegee AL
(205)727-8298

Submitted to: John Skinner
Naval Coastal Systems Center

ABSTRACT

This report discusses the work done under contract # N61331-86-Q-2011 Covert Signal Processing Using Vector Quantization. The main goals of this effort were as follows:

i) Design a signal set for continuous wave sonar transmission using the vector quantization design algorithm.

ii) Model the effects of sonar transmission through the ocean medium. The transmission models include reverberation, multipath, and transducer response.

iii) For the above designed signal set and transmission model, determine the system performance of the sonar system under different sea-state conditions.

System simulation is done for a multiple target environment under different sea-state conditions. Minimum power requirements are evaluated. Different parameters for the signal set design are studied to determine the optimum operating parameters.

Simulation results are discussed showing the effectiveness of this technique towards covert sonar systems.

1. INTRODUCTION

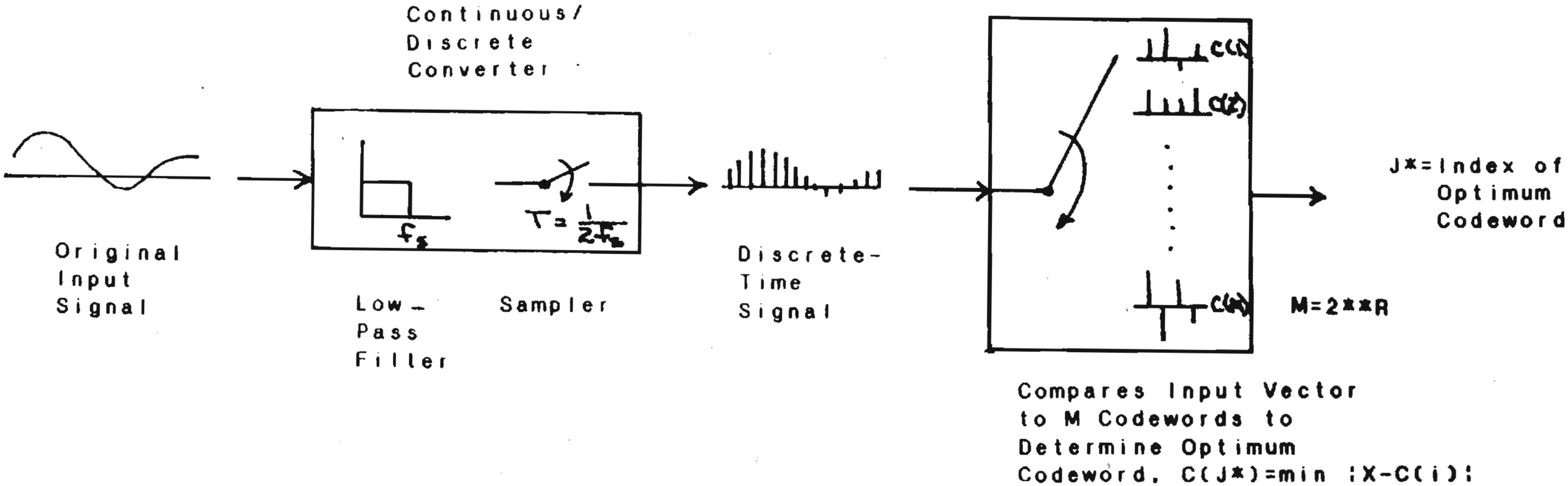
The primary goal of covert sonar systems is the detection of possible enemy targets without alerting the target of a signal being transmitted. Under this definition many techniques have been developed in an attempt of achieving this goal. Some techniques have used very narrow sonar pulses (either in frequency or time) so that detection by enemy targets can be minimized. [1] Other systems have employed frequency hopping techniques such as spread spectrum to insure minimum detection by enemy targets. [2,3] However, in each of the above cases, the sonar signal could be detected if certain parameters were known such as frequency and time duration used for the signal. A more optimum approach (at least intuitively) would be to design a covert sonar system which transmitted signals that "looked like" other signals present in the environment. If such a signal set could be designed, detection of the signal by enemy targets could very possibly be ignored due to the similarity of the sonar signal with the environment. This is the aim of the research presented in this report: to design a covert sonar system whose main aim is not the elimination of detection by enemy targets, but rather to create a covert effect by hiding the signal in the environment. Thereby eliminating detection.

The technique used in this report for covert sonar systems is called vector quantization. Traditionally, vector quantization (VQ) has been used as a digital coding technique for transmitting waveforms or parameters at lower bit rates as compared to other coding techniques i.e., pulse code modulation, delta modulation, and adaptive coding schemes. [4 - 8]. One very desirable property of VQ is that it designs a locally optimum signal set based upon a long training sequence of sampled data. The result being that the VQ signal set preserves the same statistical properties as the training sequence. Therefore, if the VQ signal set is trained on a certain sea-state environment, it would have spectral characteristics similar to that environment making it hard to detect by possible targets. Before we proceed any further it may be useful to discuss the VQ design algorithm for covert sonar systems.

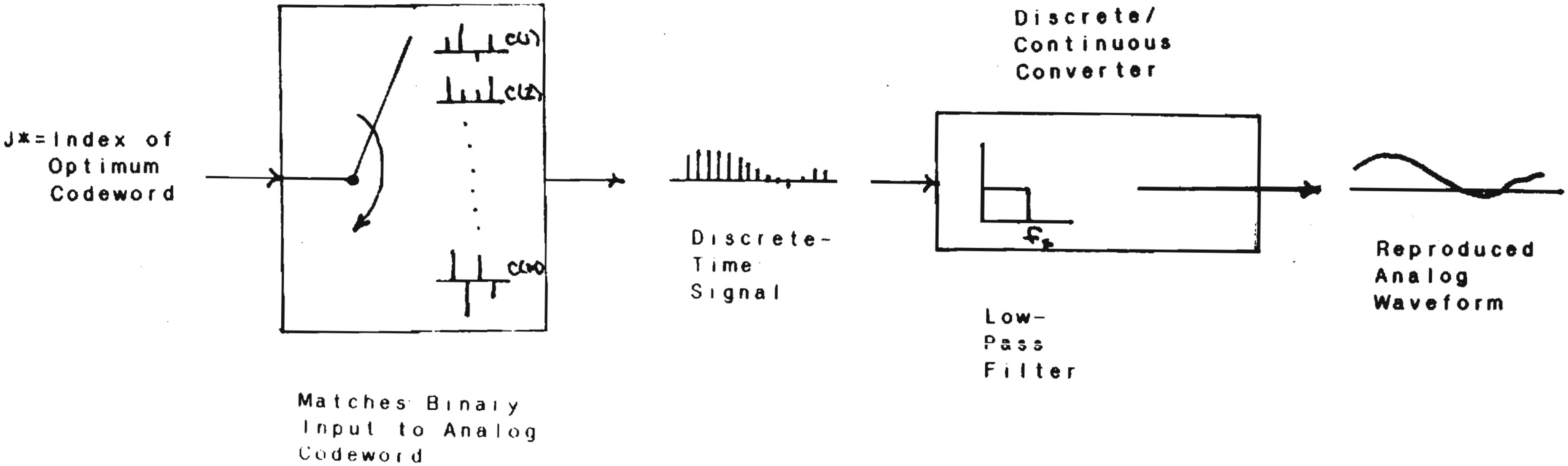
2. VECTOR QUANTIZATION

For waveform coding applications VQ is used to digitally transmit and receive a given analog input signal. The encoder acts as the analog-to-digital coverter, transmitting binary messages which represents the VQ signal set. The decoder accepts these binary messages and reproduces an analog signal from the sequence of decoded codewords. The VQ coding process for waveform signals is shown in figure 1. As shown in figure 1 vector quantization is a block coding technique rather than scalar coding. As a block coder, VQ can better match the waveform (lower distortion) and come closer to the rate-distortion limit for

ENCODER



DECODER



coding a given signal. [9]

The VQ process for speech coding can be described as follows: 1)an input block of samples (referred to as an k-dimensional input vector) is compared to a collection of predetermined k-dimensional patterns called codewords, 2)the index of the codeword closest to the input vector is binary encoded and sent to the decoder, 3)the decoder receives the binary index and outputs the k-dimensional pattern corresponding to this index (the encoder and decoder have access to the same VQ codebook). See Appendix A for a numerical example of the VQ coding process.

The distortion associated with VQ coding appears between the original input vector and it's closest codeword. As the number of codewords increase there is less distortion between the input sequence and its closest codeword (the upper limit being an infinite number of codewords yielding zero distortion).

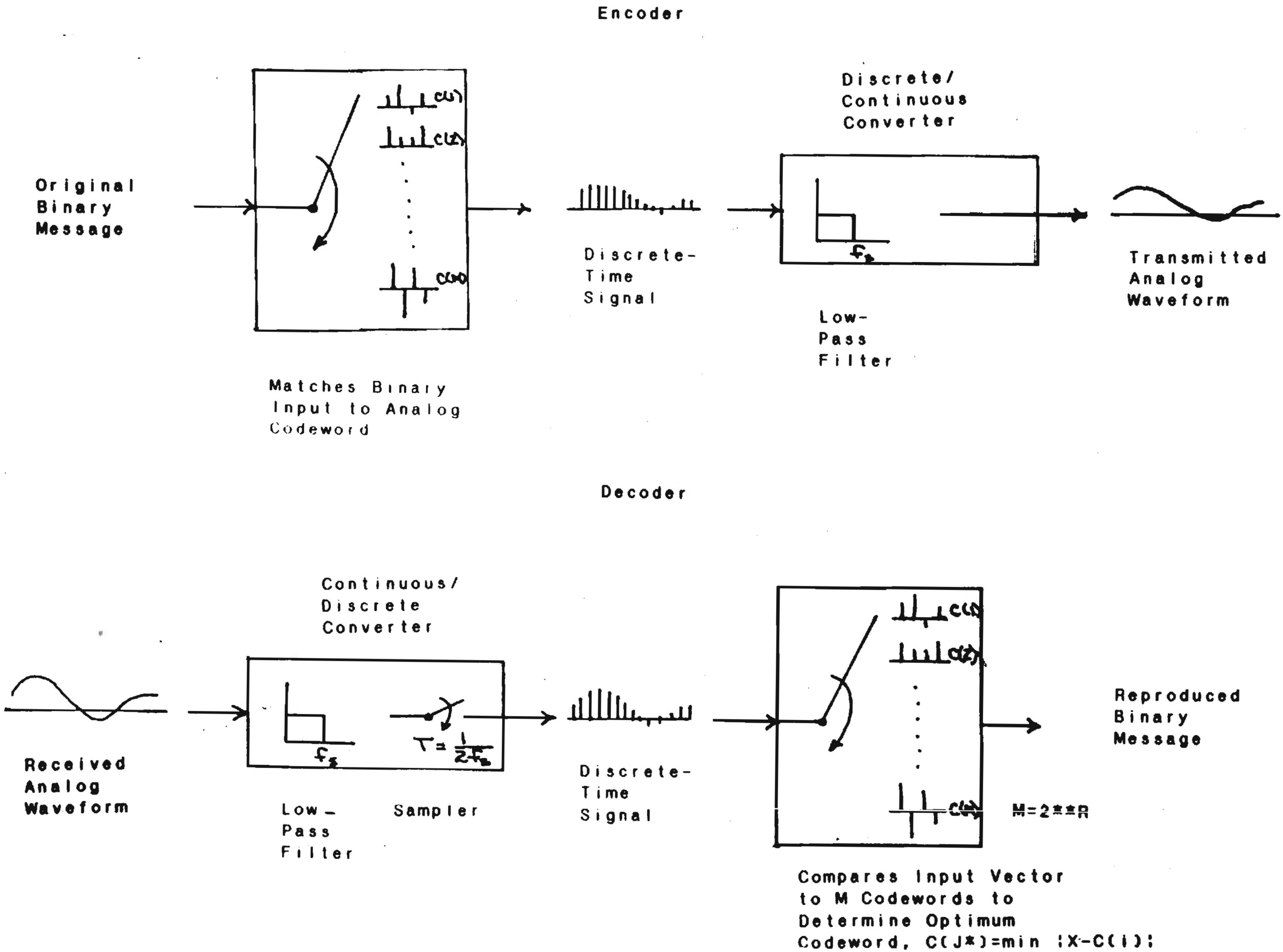
For covert systems application, the VQ encoding and decoding processes are reversed: 1)The encoder accepts an input binary message. The sequence of binary messages can be chosen to yield a typical analog output sequence. This issue will be discussed in more detail later in this report. The binary message corresponds to a sequence of k-dimensional codewords stored at the encoder. 2)The encoder then transmits the sequence of analog codewords as sonar signals. 3)The decoder (after normalizing for reverberation) compares the received analog signal to its collection of stored codewords and outputs the corresponding binary message. (See figure 2)

Using this technique, the transmitted signal (or sequence of codewords) are exposed to the desired destination as well as possible undesirable sources. However, as stated previously, the codewords can be designed to resemble environmental noise (or other sources such as biological marine life or weather conditions). This minimizes the possibility of undesirable sources recognizing the transmission as intelligible signals.

The method used to design the codewords to resemble environmental noise is called the VQ design algorithm. It can be outlined as follows:

> Step 1) Initialization: Given a long input training sequence X(n) (1 <= n <= L), and an initial codebook of P codewords C(j) (each codeword being k samples long),
>
> Step 2) Training Sequence Encoding: Encode each k-dimensional input block to its nearest codeword using the Euclidean-distance distortion measure.

Figure 2 - Vector Quantization for Covert Systems



Step 3)Codeword Updating: Replace each codeword by the centroid of all input vectors which mapped to it.

Step 4)Calculate the distortion associate with the encoding process of step 2. If the change in the distortion relative to previous encodings is below some predetermined threshold, stop. If not go to step 2 and repeat the process.

A numerical example of the VQ codebook design is shown in Appendix B.

Given that the convergence threshold of step 4) is sufficiently small, the final codebook is well matched to the input training sequence. In fact, the resulting codebook is a collection of averages of the training sequence. Using a training sequence of environmental sea-state noise, the codewords are guaranteed to look like average noise signals.

3. COVERT SONAR VECTOR QUANTIZATION

The system model used for covert sonar vector quantization (CSVQ) is shown in figure 3. This model is composed of the following sections:

- Signal Set / Noise Model Design
- Signal Transmission

Figure 3 - CSVQ System Description

Signal Set / Noise Model Design

↓

Signal Transmission

↓

Receive Reverberation/ Target Echo/Plus Noise

↓

Normalize Return Signal

↓

Decode Return Signal to Make Target/No Target Decision

- Receive Signal Plus Noise
- Normalization of returned Signal
- Decoding Normalized Signal
- Comparison of Decoded Sequence With Transmitted Sequence to Make Target / No Target Decision

Signal Set and Noise Model Design

In order to design the VQ signal set the noise sequence must first be modeled. The model used for generating the noise sequence was a white gaussian noise source filtered through the sea-state spectral model supplied by NCSC. [10] The resulting process yields a sample sequence of sea-state noise. The bandwidth chosen for the sea-state spectral model was 20KHz. This value was chosen according to the transducer frequency model supplied by NCSC. [11]

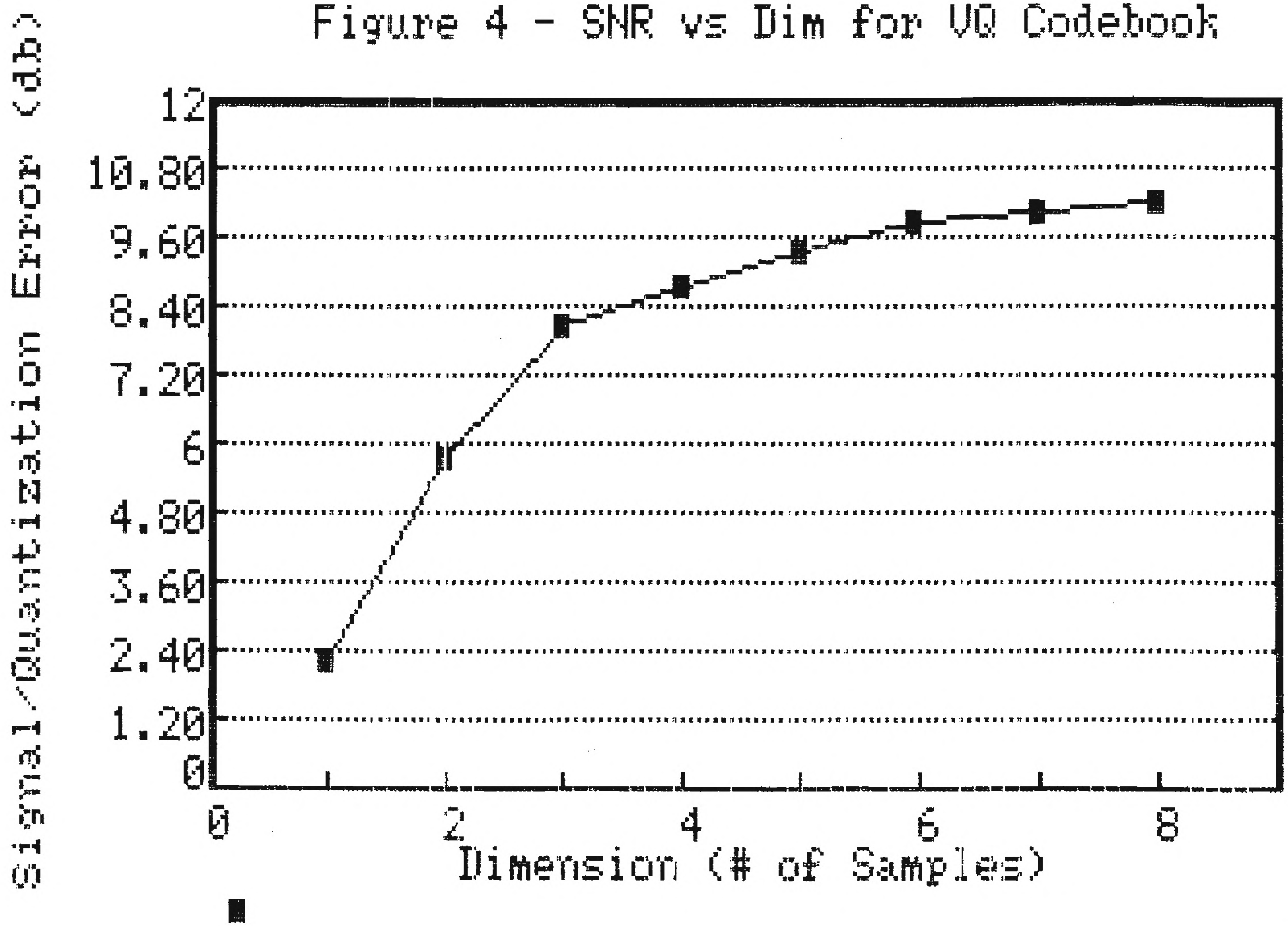
The VQ design process uses a training sequence of data long enough to represent a "typical" training sequence of data. For different applications "typical" lengths can range from 1,000 to 1,000,000 samples. For this case the training sequence size was chosen to be 100,000 samples. This size will insure that the signal set amply represents the noise sequence. (One rule of thumb in using vector quantization is to have at least 50 training vectors for each codeword vector. [12])

The next set of parameters are the vector dimension - k and the number of codewords used - M. Increasing the vector dimension separates the codewords by a greater euclidean distance. Increasing the number of codewords increases the signal-to-quantization error of the noise sequence representation. The dimension size varied from 1 to 8 (1 being scalar quantization). The number of codewords varied from 2 to 256. Both these factors affect the complexity of the system. The computational load is linearly proportional to both the number of codewords and dimension size. This issue will be revisited later in this report.

In summary of the VQ signal set design, a noise sequence was generated of 100,000 samples. This noise sequence was used as a training sequence for the VQ design algorithm. The algorithm designed a total of eight different signal sets or codebooks. These codebooks will be used as transmission signals during the next phase of CSVQ simulation. The quantization noise SNR versus dimension for each codebooks is shown in figure 4.

Concerning the modeling for the sea-state noise environment, the same noise model was used as above to create 100,000 additional noise samples. These noise samples will be used as environmental sea-state values in the receive portion of the simulation. An important point is that the two noise sequences (one for the signal set design and the other for the environment) are independent of each other but display the same spectral properties. This fact

Figure 4 - SNR vs Dim for VQ Codebook



will become important in the decoding portion of the simulation.

Signal Transmission, Reverberation, and Noise

The goal of this section is to describe the transmission scheme used for the CSVQ system. Given a VQ codeword sequence to transmit: the following processing steps were involved:

i) The VQ codebook sequence was transmitted one sample at a time into the volume.

ii) The reverberation levels (volume and surface) due to each transmitted sample was calculated.

iii) Noise was added to these collections of signals to form a joint signal/reverberation/noise returned signal.

On a per sample basis the VQ codewords were sent into the volume. Each codeword was transmitted as it appeared in the original training sequence. Therefore, the codeword sequence matched the training sequence thereby preserving the spectral properties of the sea-state noise in which it was trained on.

The reverberation levels were calculated on a per sample basis. This implies that for K samples transmitted K reverberation levels must be computed to give a total return signal level. Independent sea-state noise was added to this signal to represent the source of all signals present in the environment. The equations used for surface and volume reverberation levels are as follows:

VOLUME

RL = Sv + SL - TL + 10 LOG(C*tp*Q/2)

where: Sv - Volume Scattering Coefficient (-60 db)

SL - Source Level (Varied from 80 - 160 db)

TL - Transmission Loss (1/R**2)

C - Sound Velocity (1440 m/s)

tp - Pulse Width (1/fs)

fs- Sampling Frequency (40 KHz)

Q - Effective Beamwidth (10 degrees) [13]

SURFACE/BOTTOM

RL = Ss,b + SL - 3/2 TL + 10 LOG(C*tp*Q/2)

where: Ss,b - Surface/Bottom Scattering Coefficient (-80 db)

Y - Effective Two Way Azimuth Beamwidth (180 Degrees) [14]

For the return energy level due to target echo the following equation was used:

TARGET ECHO

$$EL = TS + SL - 2\ TL$$

where: TS - Target Strength (Varied from 15-25 db)

For all the above equations reverberation levels were calculated on a sample by sample basis, giving a total return signal level for the CSVQ system. For the total returned signal, processing steps were made in attempt to recover the original transmitted signal. The primary aim of the decoding process is as follows: if the returned signal can be decoded to the original signal then the probability of a target being present is high. While if the returned signal can not be decoded to the original, then there is low probability of a target being present. The logic of the above statements is related to two important sonar system parameters - probability of detection Pd and probability of false alarm Pfa. This matter will be revisited later in this report.

Normalization and Decoding

The received signal is the linear combination of volume/surface reverberation plus possible target echo plus noise. This joint signal must be normalized for the presence of targets in the volume. The method used for this normalization is to the following:

i) Subtract the volume/surface reverberation from the returned signal.

ii) Multiply the remaining signal by r**2 to normalize for distance.

For simulation purposes, each transmitted sample creates a sequence of reverberation values as a function of time or distance. Also, each sample creates a target echo according to the distance and strength of the target. The reverberation level of each sample creates an infinite sequence of reverberation samples that die off exponentially as 1/r**2. The target echo yields a residue that is not subtracted away from the normalization process. This residue is the quantity which is sent to the decoder.

Before we move to the decoding section, it is important to evaluate the implications of step ii) above. The reverberation level is subtracted away. However, the noise level remains and is multiplied by r**2 along with possible target echo. This implies that for targets long distances away, returned signal echo becomes too small in comparison to the environmental noise. Noise levels in close proximity to the submarine is multiplied by r**2 just as the weak target echo is multiplied. For large r this multiplication factor dominates the noise while only recovering the transmitted signal to its original level. Therefore we would expect that some outside limit exists as to the distance that targets can be detected. Simulation results will support this conjecture later in this report.

Decoding

Once the signal has been normalized, the decoding process can begin. The CSVQ system asks the question "Does a target of strength K exist at distance L"? The processing steps involved in answering this question are as follows:

i) Check for target strength K at distance L

ii) Normalize the signal set for distance K

iii) Decode the remaining sequence using the CSVQ decoding algorithm for target strength L

iv) Does the decoded sequence match the original sequence?

v) Increment K, go back to i).

iv) Increment L, go back to i).

The main train of thought for the above processing steps is to decode the incoming signal sequence assuming a target exists of strength K at distance L. If the decoded sequence matches the original sequence a target exists. If the decoded sequence does not match the original sequence a target does not exist. For the CSVQ system simulations, K varied from 15 to 25 db, L varied from 1 to 2500 meters. The resolution of L depends upon the sampling rate of the transmitted and received signal. Using 32,000 samples per second the range resolution is .05 meters per sample. Therefore, the CSVQ system looks for targets in the range of

1 to 2500 meters with a resolution of .05 meters. The target strength resolution incremented by 1 db. So the CSVQ system looks for targets in the volume between 15 and 25 db with increments of 1 db.

Concerning step iv) for the above process, the question arises as to what does "match the original sequence" mean? If we constrain the decoded system to match the original sequence perfectly, the probability of false alarm may be very low at the cost of having a low probability of detection. If we allow a low percentage of matches between the original and decoded sequence the probability of detection may be high at the cost of probability of false alarm rising also. Using this decoding process Pd and Pfa rise and fall with how we decode the signal. Appendix C discusses experimental ways in which we can determine Pfa and Pd for the CVSQ system.

The comparison in step iv) above suggests a new parameter which should be observed: the occurrence of correctly decoded vectors for a given strength/range simulation.

sigma = number of correctly decoded vectors/
total number of vectors transmitted
0 <= sigma <= 1

Of course the value of sigma will be computed for a finite time window or blocks of samples rather than an infinite duration associated with a continuous wave system. Referring to the discussion above high sigma values suggests the presence of a target, while low sigma values suggests no target present. For our simulations we will not use hard decisions on making a target / no target based on sigma. Instead we will show the sigma values corresponding to different target distribution scenarios.

4. Simulation Environment and Results

The programming environment used for simulation was on a Micro VAX II computer with an ULTRIX (UNIX look-alike) operating system. All program development was done with fortran 77 source code. The data files were both formatted and unformatted depending upon the file size. The CSVQ system was composed of modular programs totaling 18 programs with over 3,000 lines of code. A listing of the source programs are shown in Appendix D. Appendix D also describes the purpose for each program.

The main goal of the simulations was to determine the behavior of the CSVQ system as certain parameters change. The parameters of interest were dimension size of codebook vectors, total number of codewords, average transmission power, and SNR both at transmission and reception of the CSVQ signal.

The dimension size was chosen to vary between 1 and 8.

While the codebook size varied between 2 and 256 codewords. The relationship between dimension size and codebook preserved a constant rate determined by:

$$M = 2^{**}(k^{*}r)$$

where: M = Number of codewords

k = dimension size

r = rate in bits per sample

(1 bit per sample)

This relationship was adopted due to work done with VQ waveform coding. From an information theory point of view, keeping r constant means that the same amount of information is contained in the sonar pulse regardless of dimension size. The dimension/codebook size pairings used is shown in figure 5.

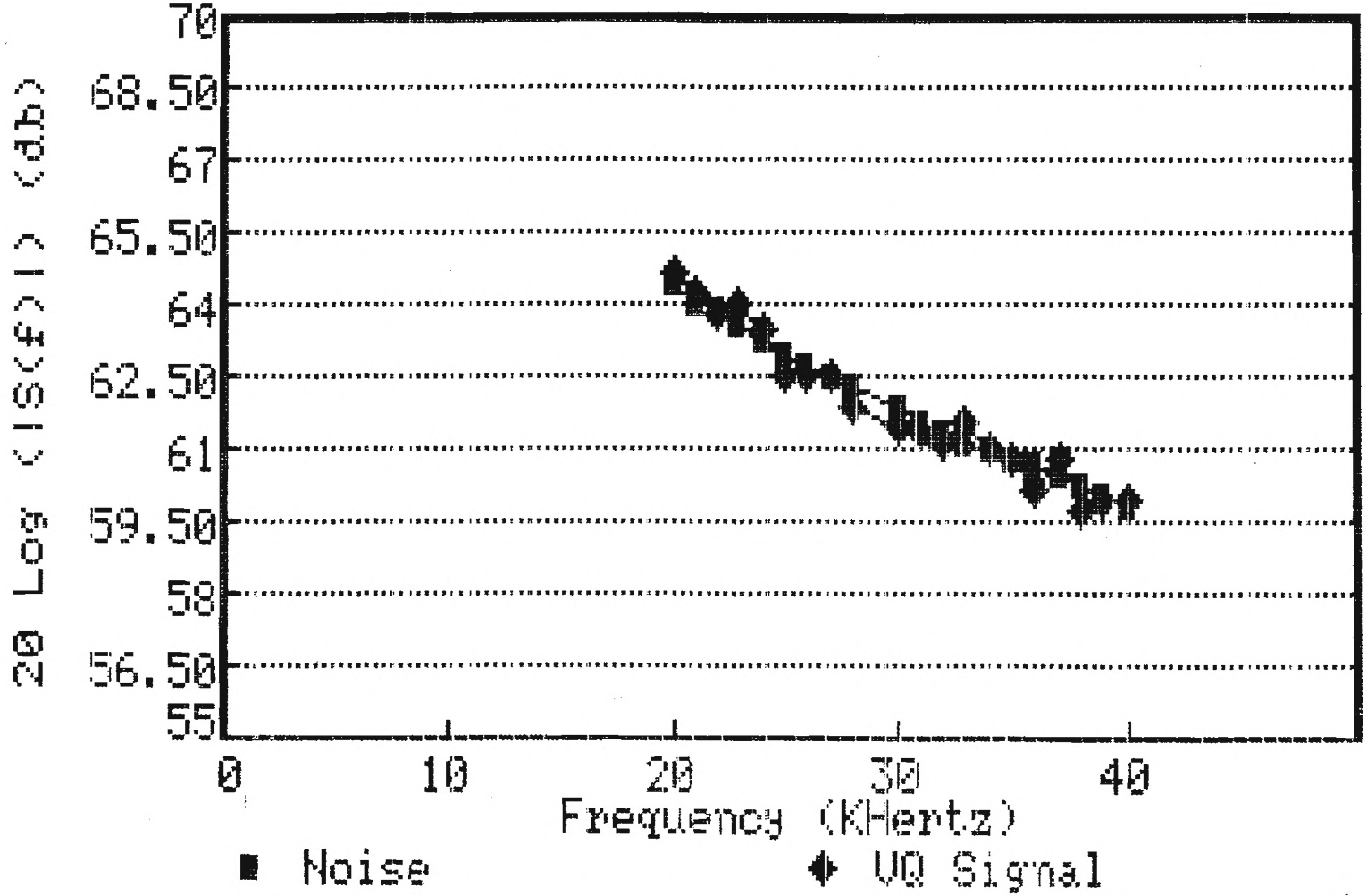
One advantage of the CVSQ system stated earlier is that the spectral properties of the codebook signal set preserves the spectral properties of the training sequence (in this case, the training sequence is the 100,000 samples of noise). The spectrums for both the noise and the codewords are shown in figure 6 (for dimension = 8).

The figure of merit for the CVSQ system is the value of sigma. As stated earlier a high value of sigma (close to 1) means that all codewords were decoded properly and there is a high probability of a target being present. A low value of sigma (close to 0) means that no codewords were present and

Figure 5 - Dimension Versus Codebook Size for the different Signal Set designs

Dimension (Number of Samples Per Codeword)	Codebook Size (Number of Different Signals in Codebook)
1	2
2	4
3	8
4	16
5	32
6	64
7	128
8	256

Figure 6 - |S(f)| for VQ Sig. and Noise



there is low probability of a target being present.

The initial simulation run for the CSVQ system was to determine what values of sigma were obtained under a no-target environment. Therefore, simulation runs were made which tested for varying dimension size, codebook size, and transmission power to determine the values of sigma. The results are shown in figures 7 - 14.

These results from figures 7 - 14 relate to the probability of false alarm for sigma values. As the dimension size increases the sigma values fall to near zero values. This gives us one result of the CSVQ simulation, i.e., to keep sigma values low under a no target environment high dimensions must be used (at least dimension sizes greater than 2). As a point of comparison, no-target sigma values at dimension 8 were no greater than .03.

The next set of simulations show the performance of the CSVQ system under a multiple target environment. Three targets were chosen with the target strength/distance distribution shown in figure 15. The sigma parameters versus signal strength in shown in figures 16 - 23 . The following points can be made:

i) Given a high enough signal power, all three targets yield high enough sigma values to indicate their presence.

Figure 7 - Sigma vs Transmit Power

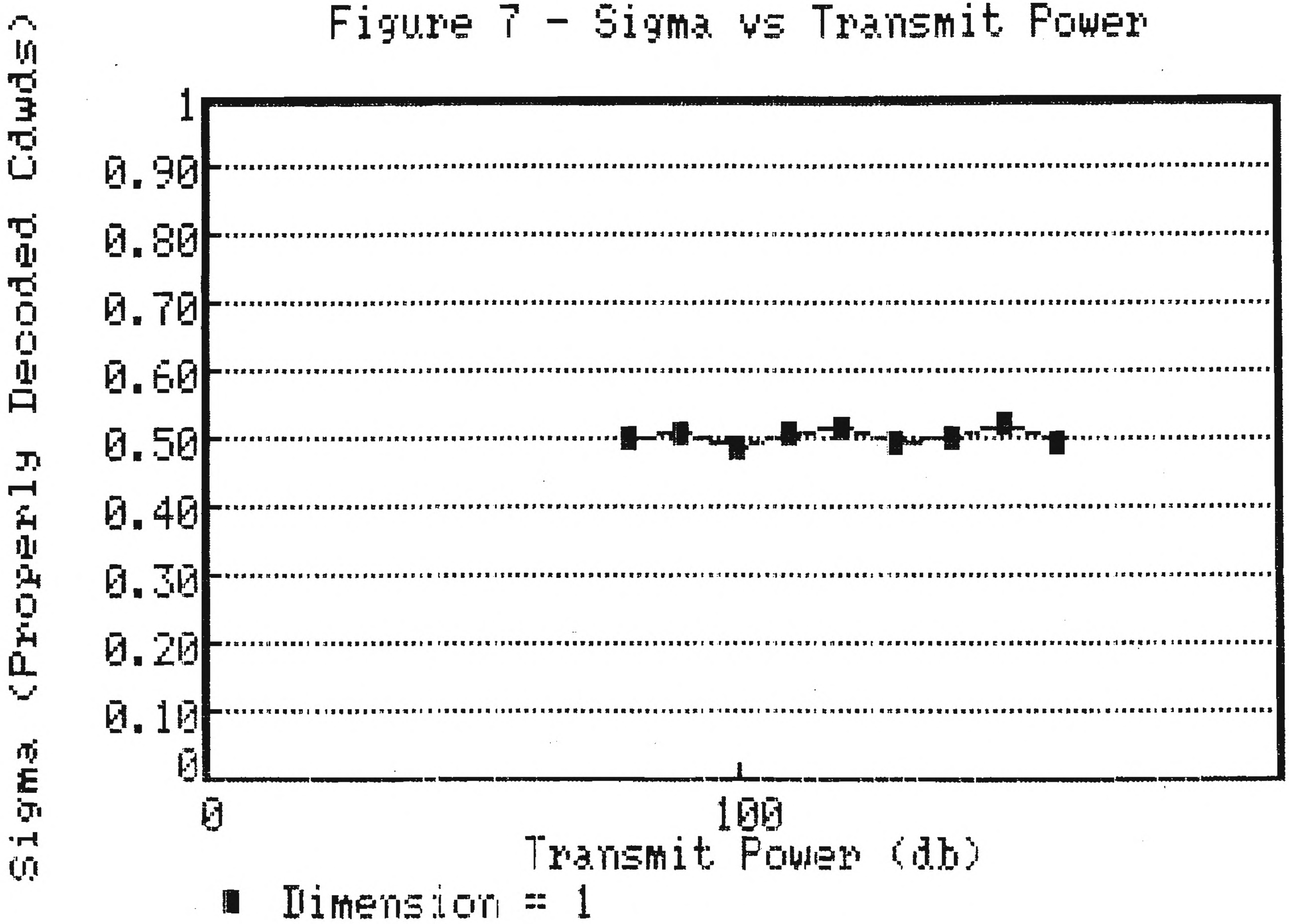


Figure 8 - Sigma vs Transmit Power

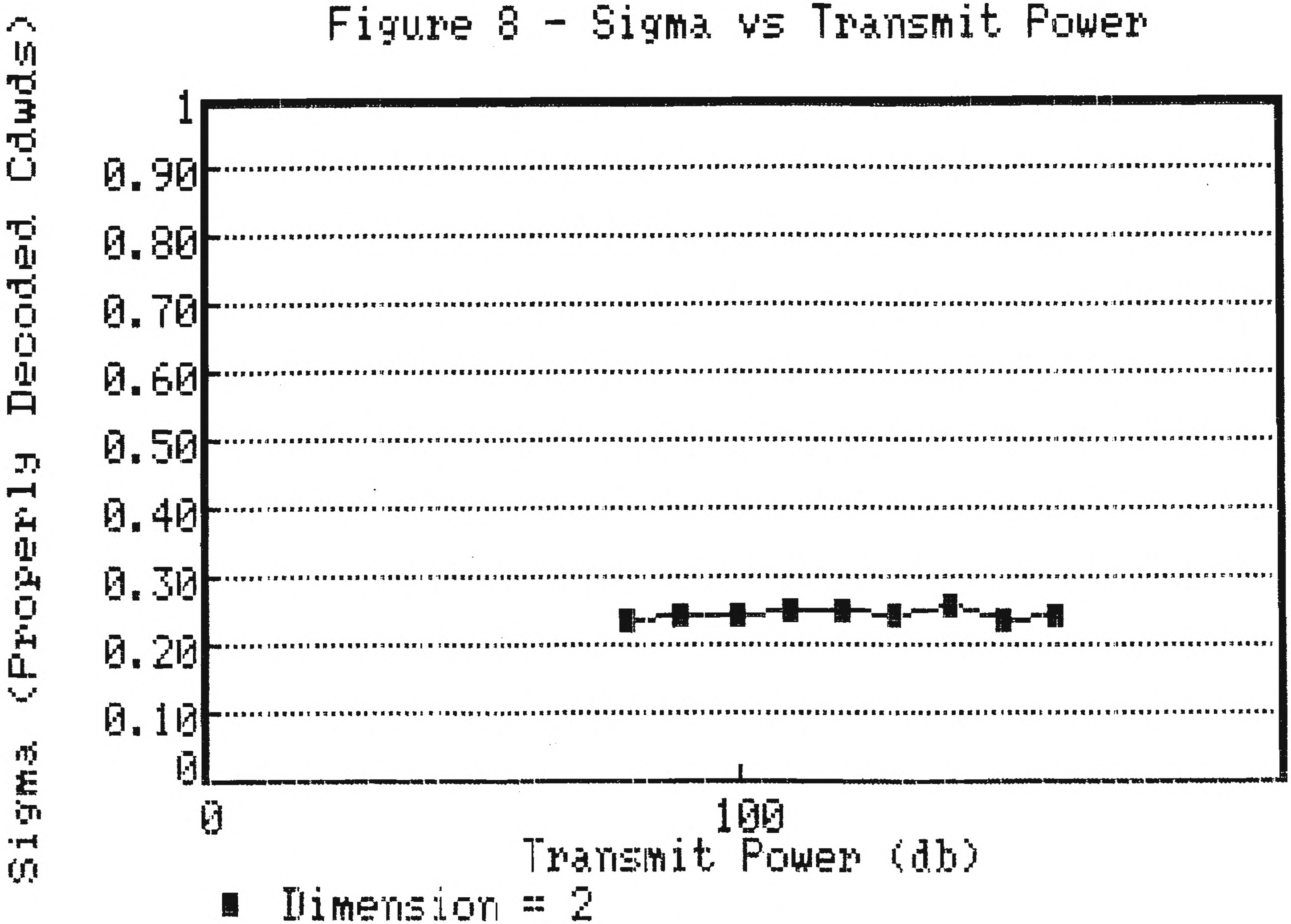


Figure 9 - Sigma vs Transmit Power

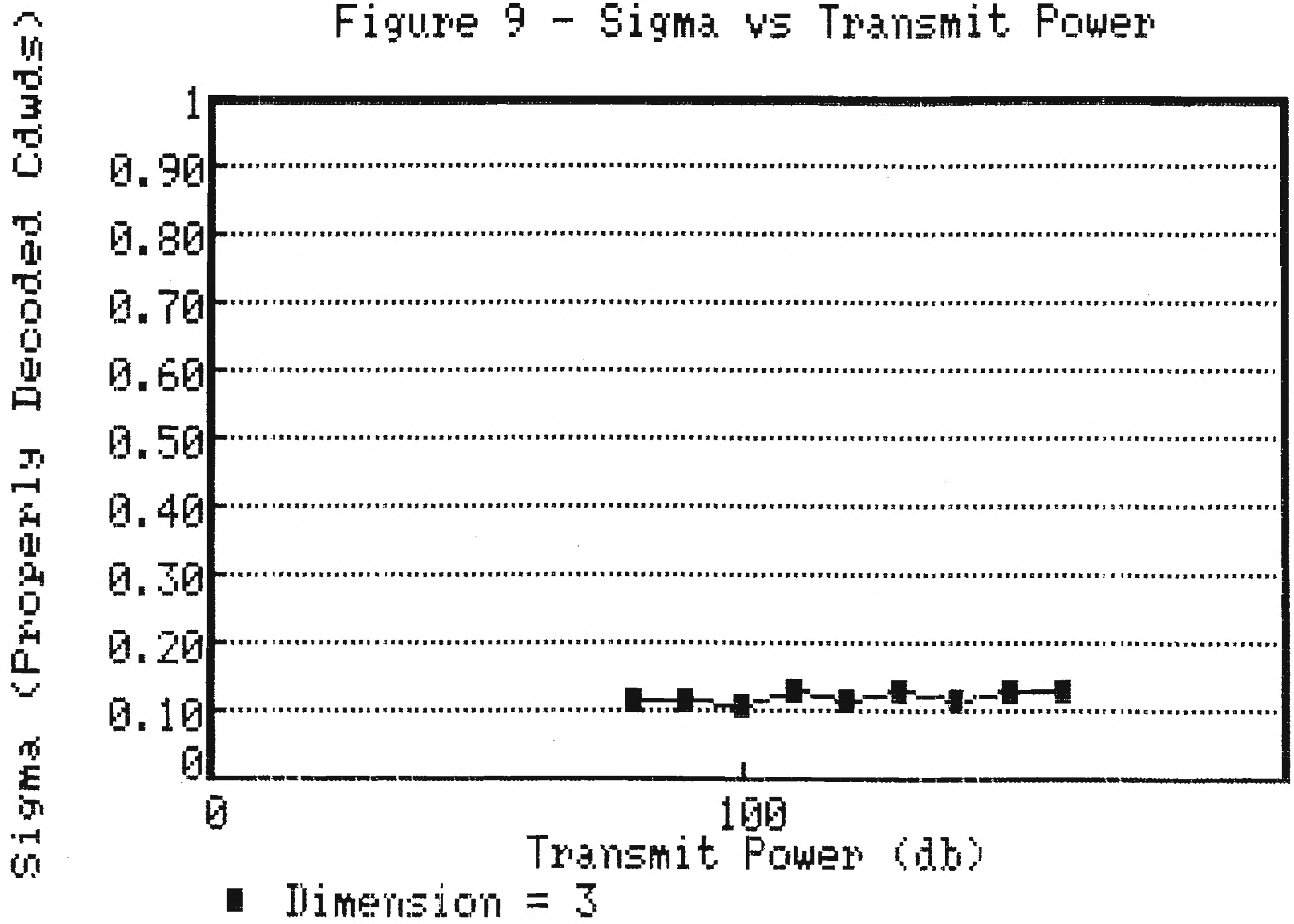


Figure 10 - Sigma vs Transmit Power

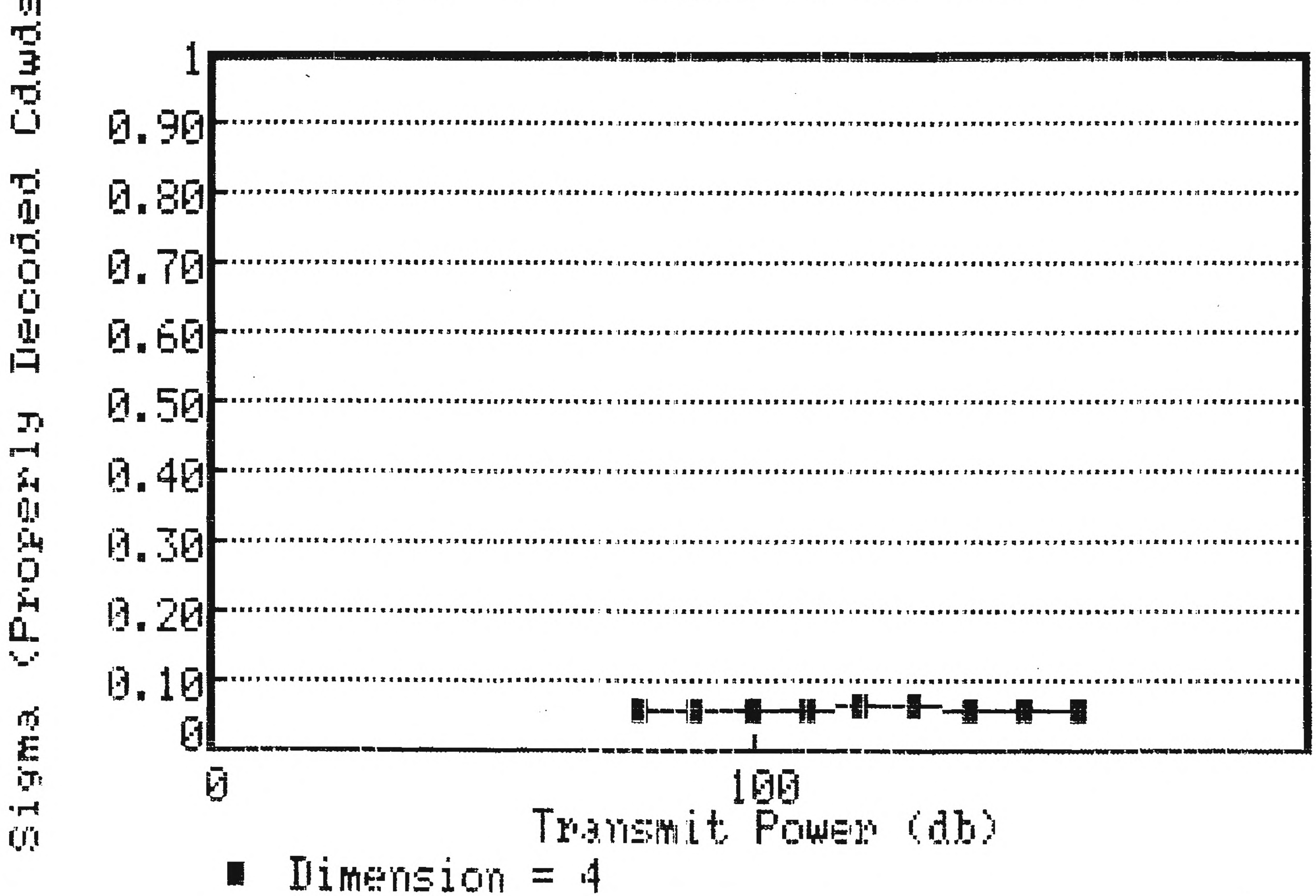


Figure 11 - Sigma vs Transmit Power

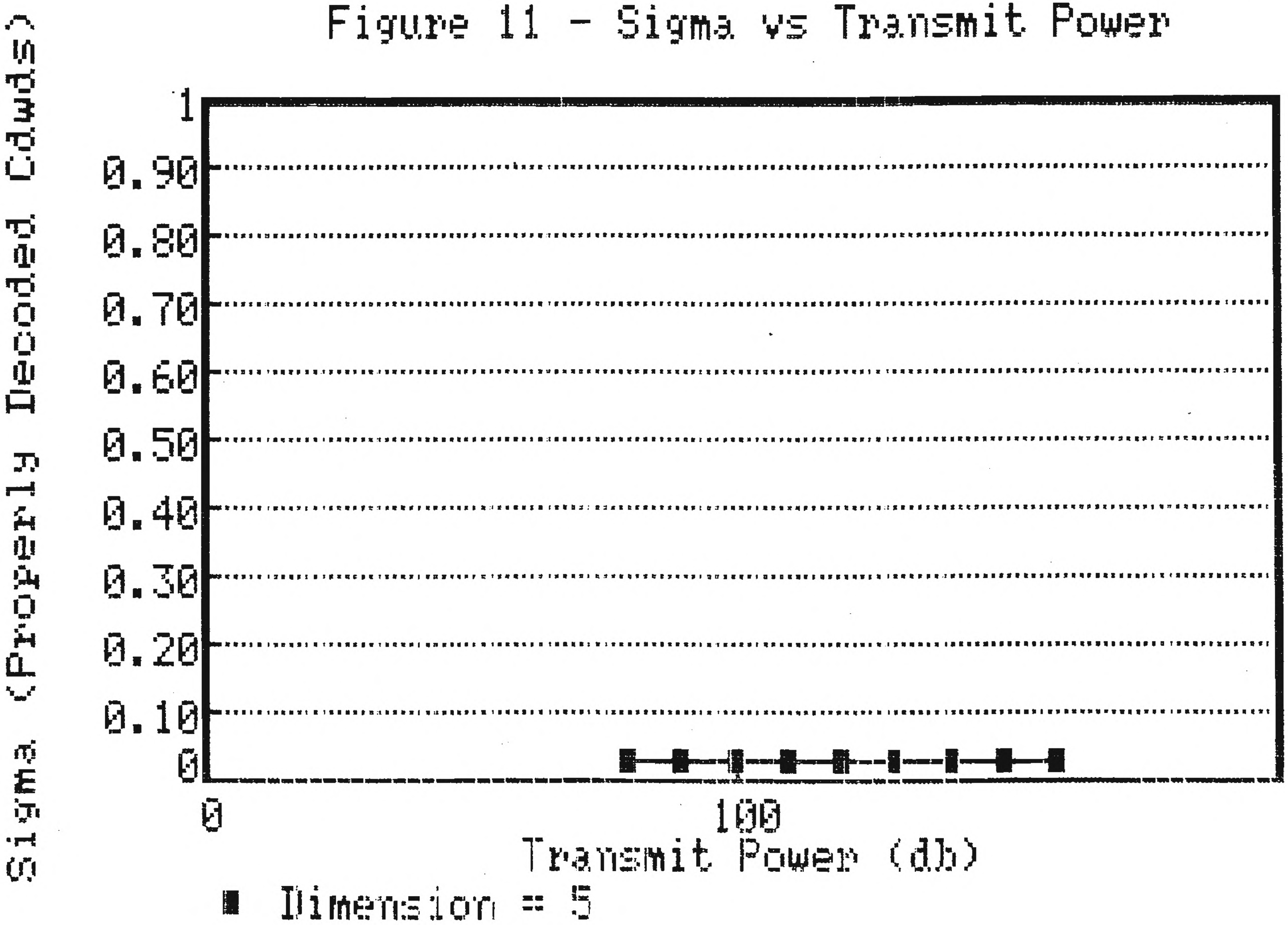


Figure 12 - Sigma vs Transmit Power

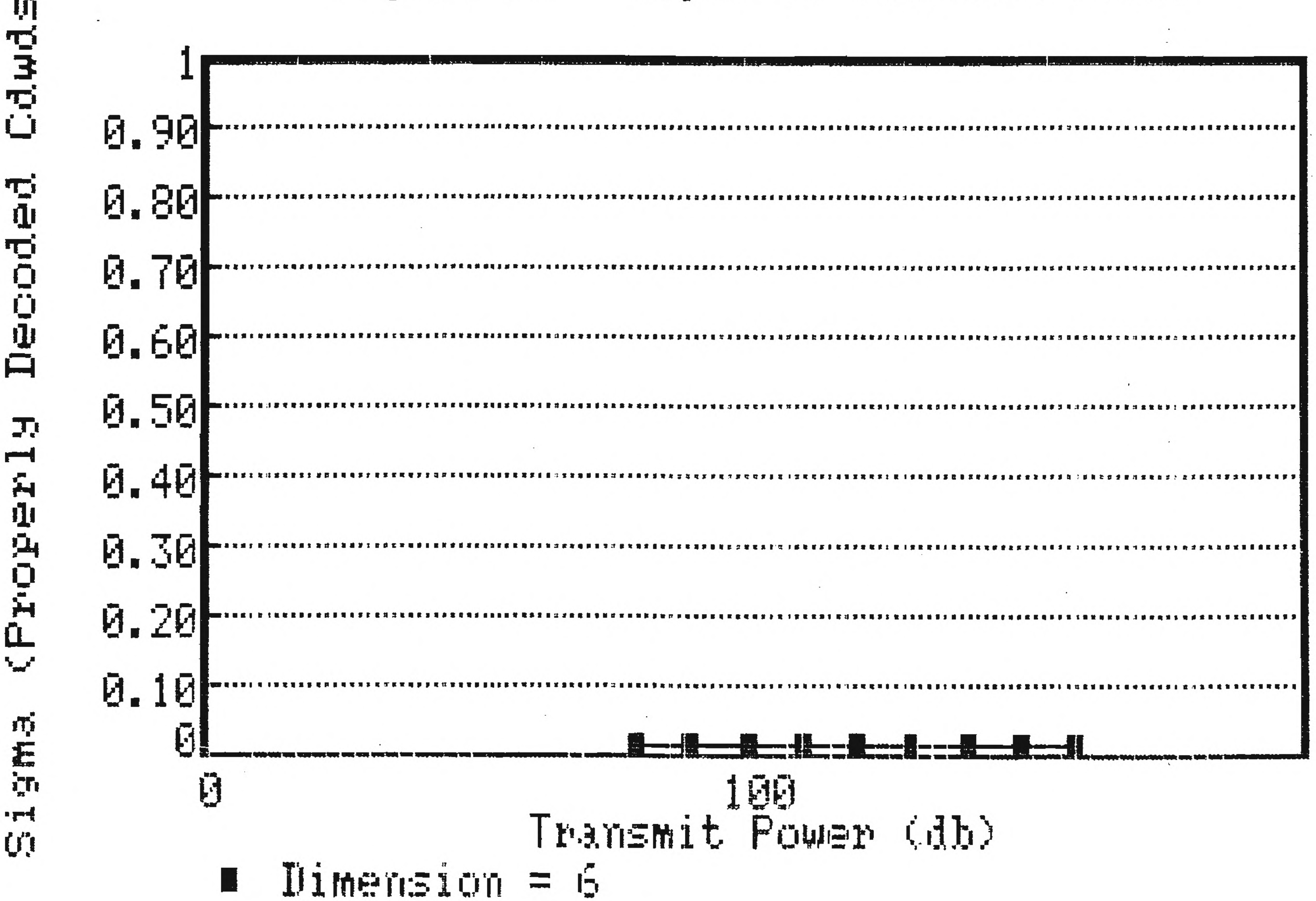


Figure 13 - Sigma vs Transmit Power

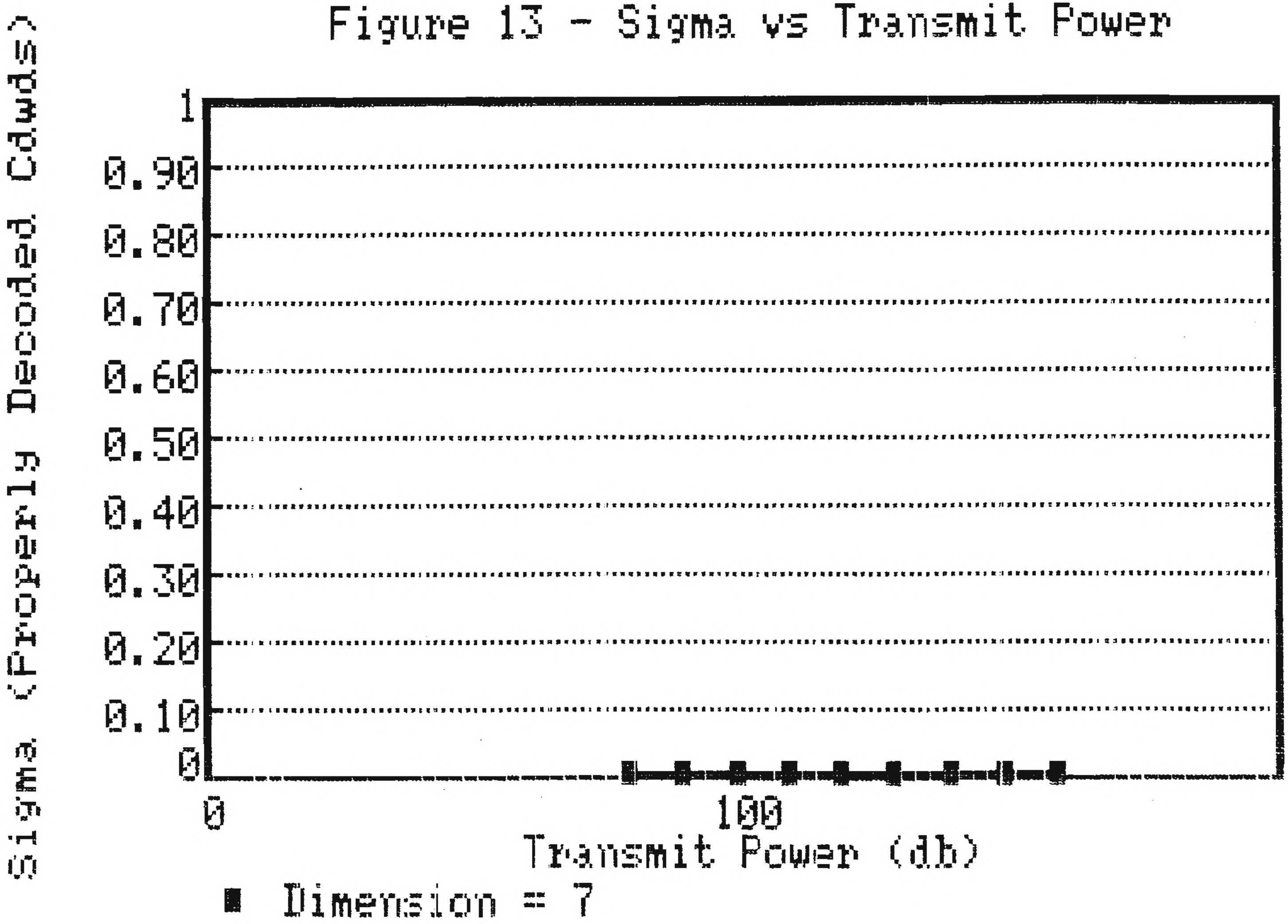


Figure 14 - Sigma vs Transmit Power

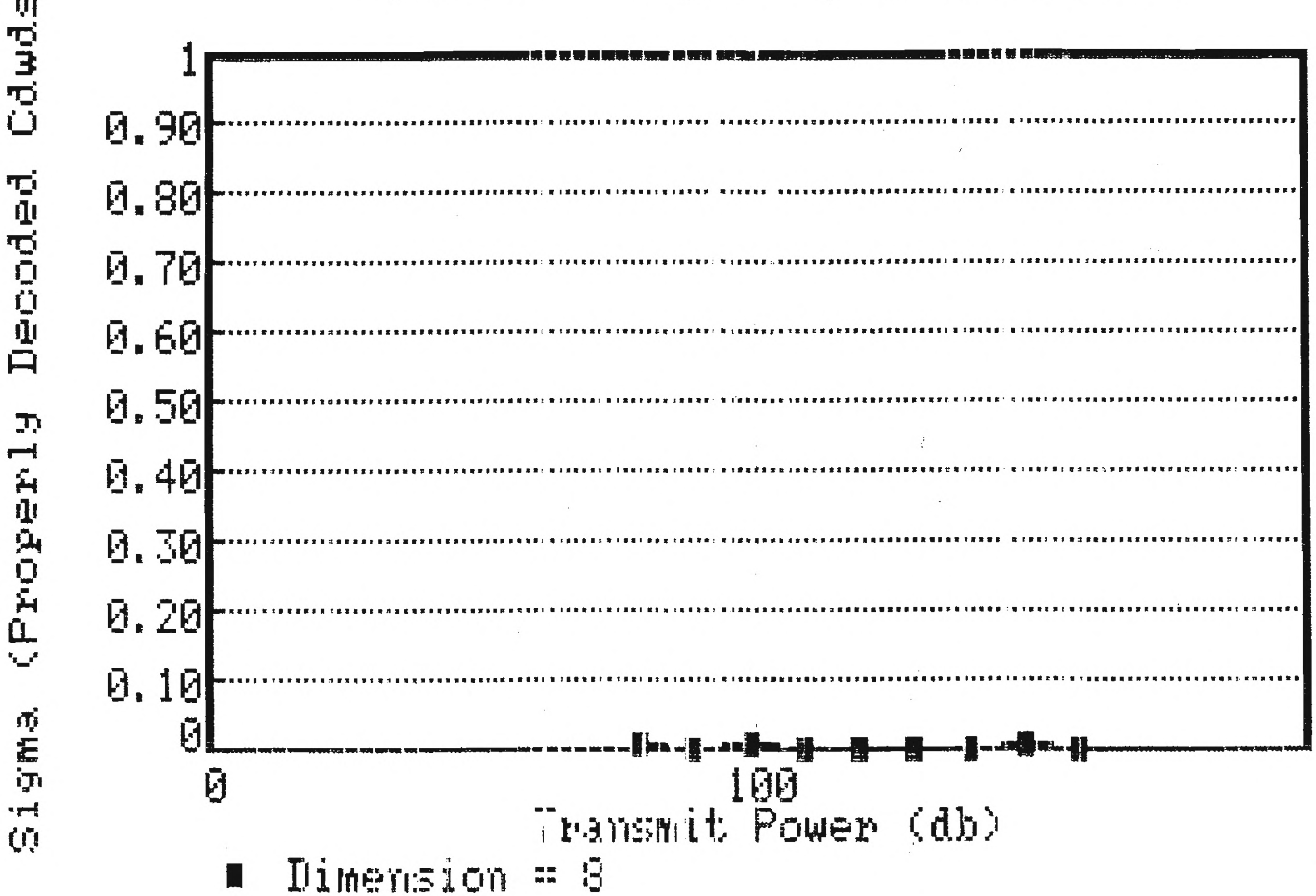
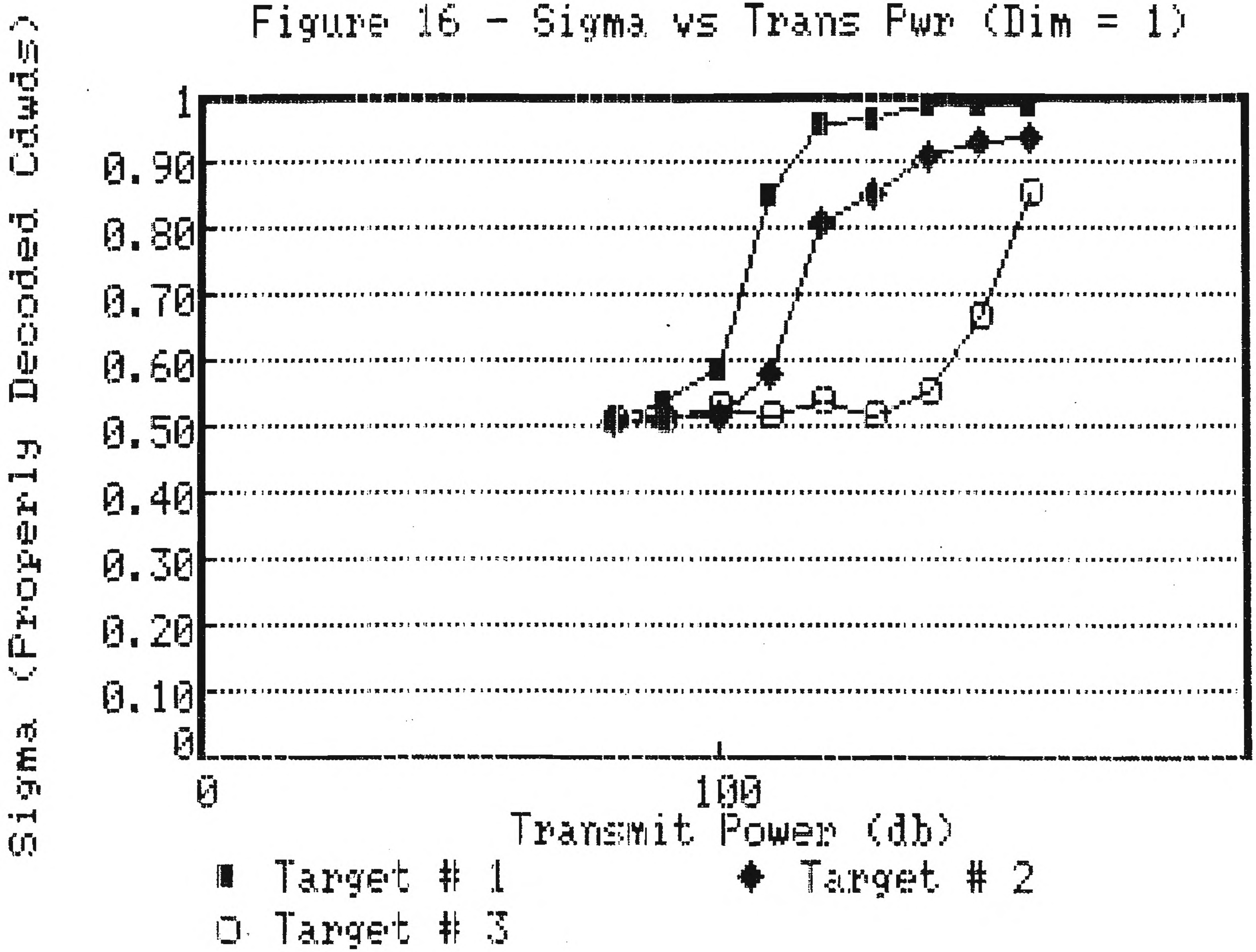


Figure 15 - Target Strength / Distance Distribution for CSVQ Simulation

Target #	Strength (Decibels)	Distance (Meters)
1	20	120
2	23	200
3	17	440

Figure 16 - Sigma vs Trans Pwr (Dim = 1)



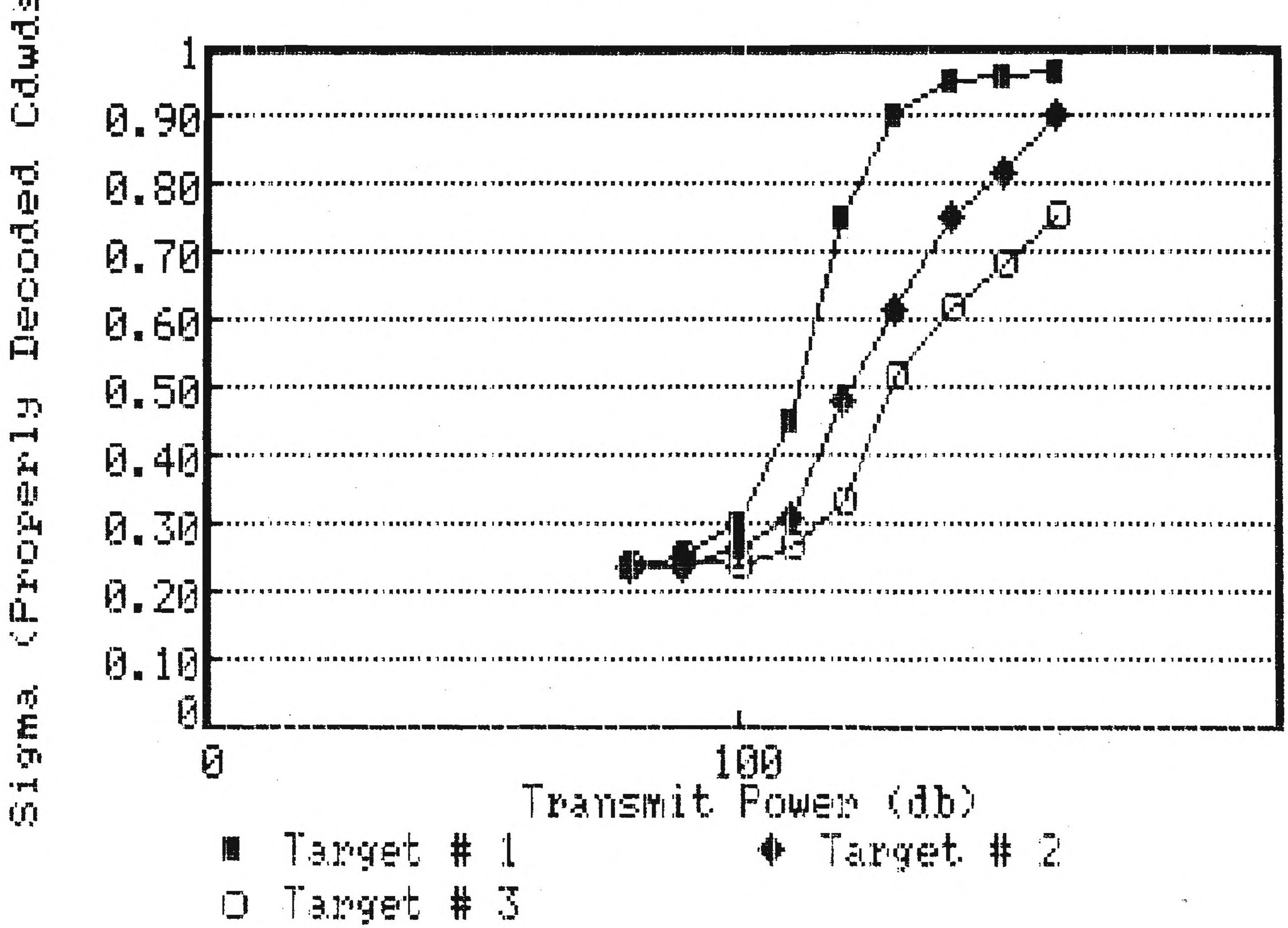


Figure 17 - Sigma vs Trans Pwr (Dim = 2)

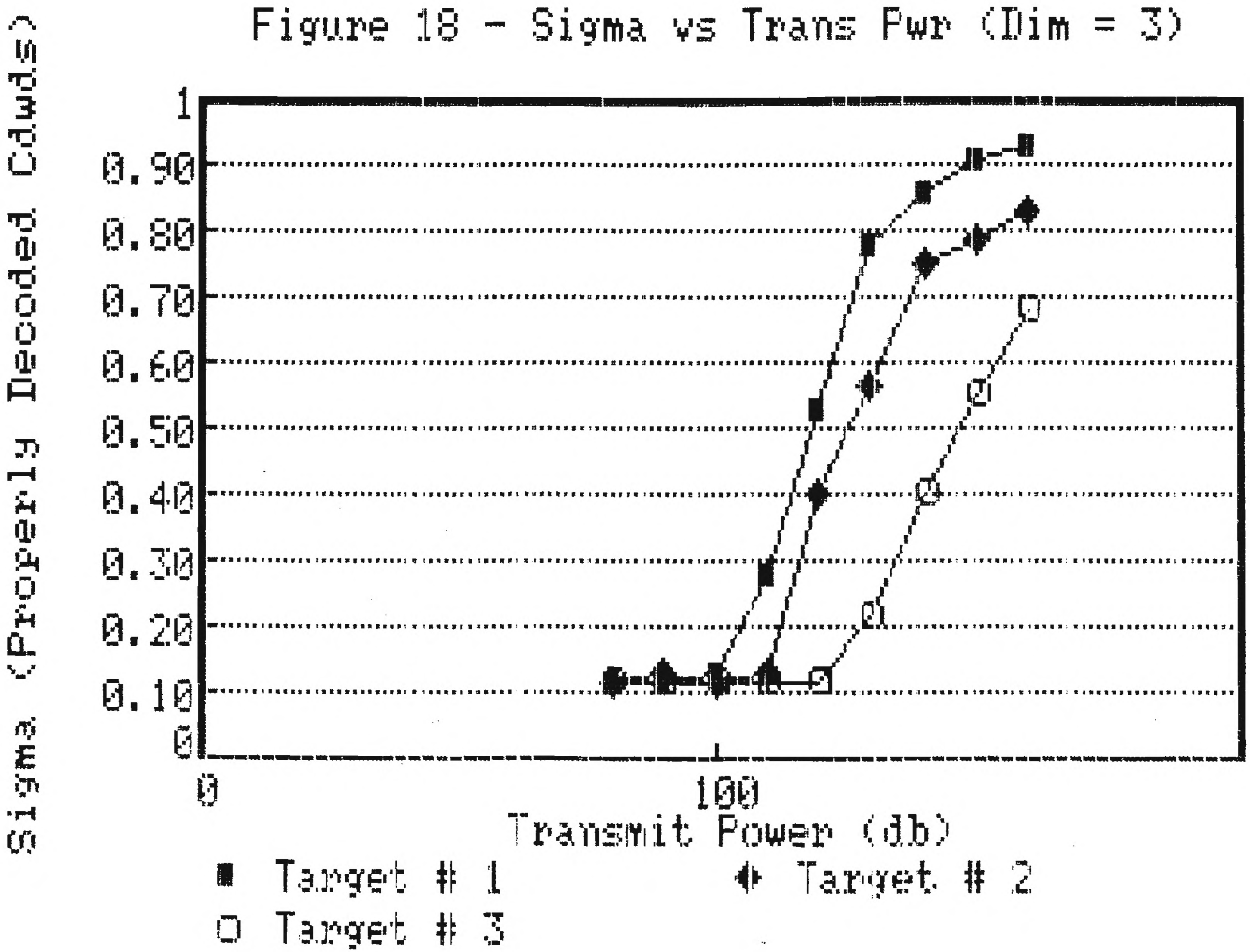


Figure 18 - Sigma vs Trans Pwr (Dim = 3)
Sigma (Properly Decoded Cdwds)
1
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0
0
100
Transmit Power (db)
Target # 1
Target # 2
Target # 3

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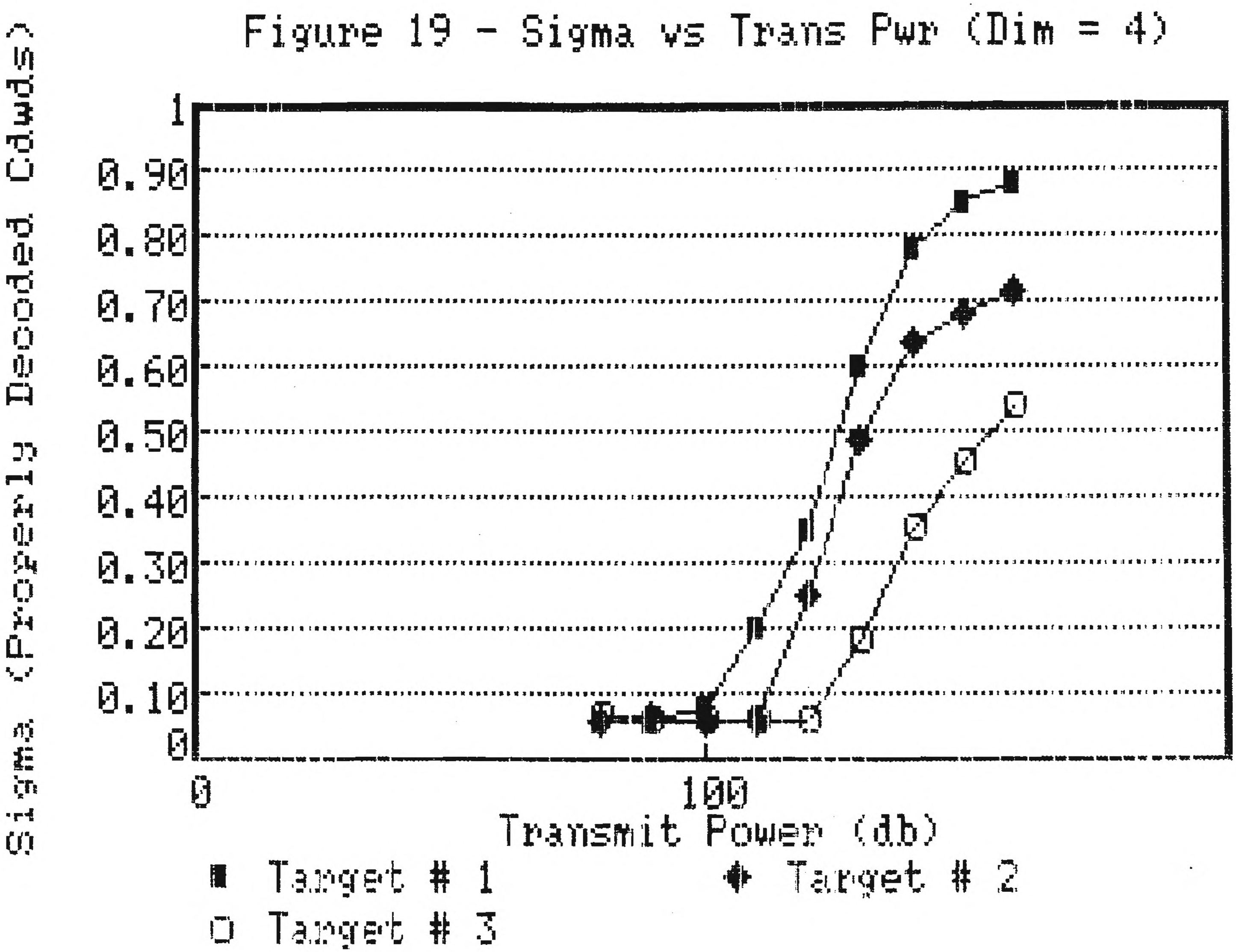


Figure 19 - Sigma vs Trans Pwr (Dim = 4)
Sigma (Properly Decoded Cdwds)
1
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0
0
100
Transmit Power (db)
Target # 1
Target # 2
Target # 3

Figure 20 - Sigma vs Trans Pwr (Dim = 5)

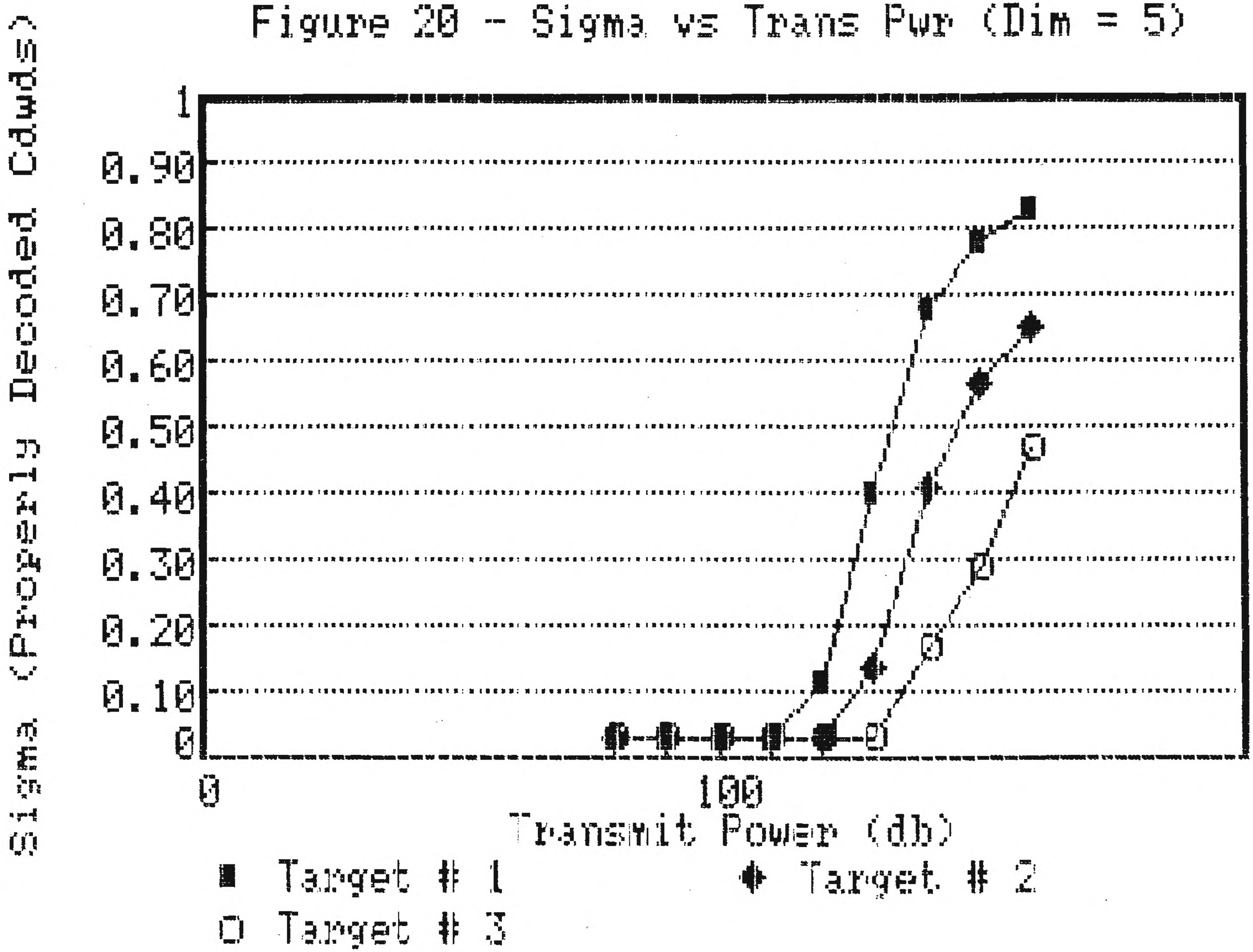


Figure 21 - Sigma vs Trans Pwr (Dim = 6)

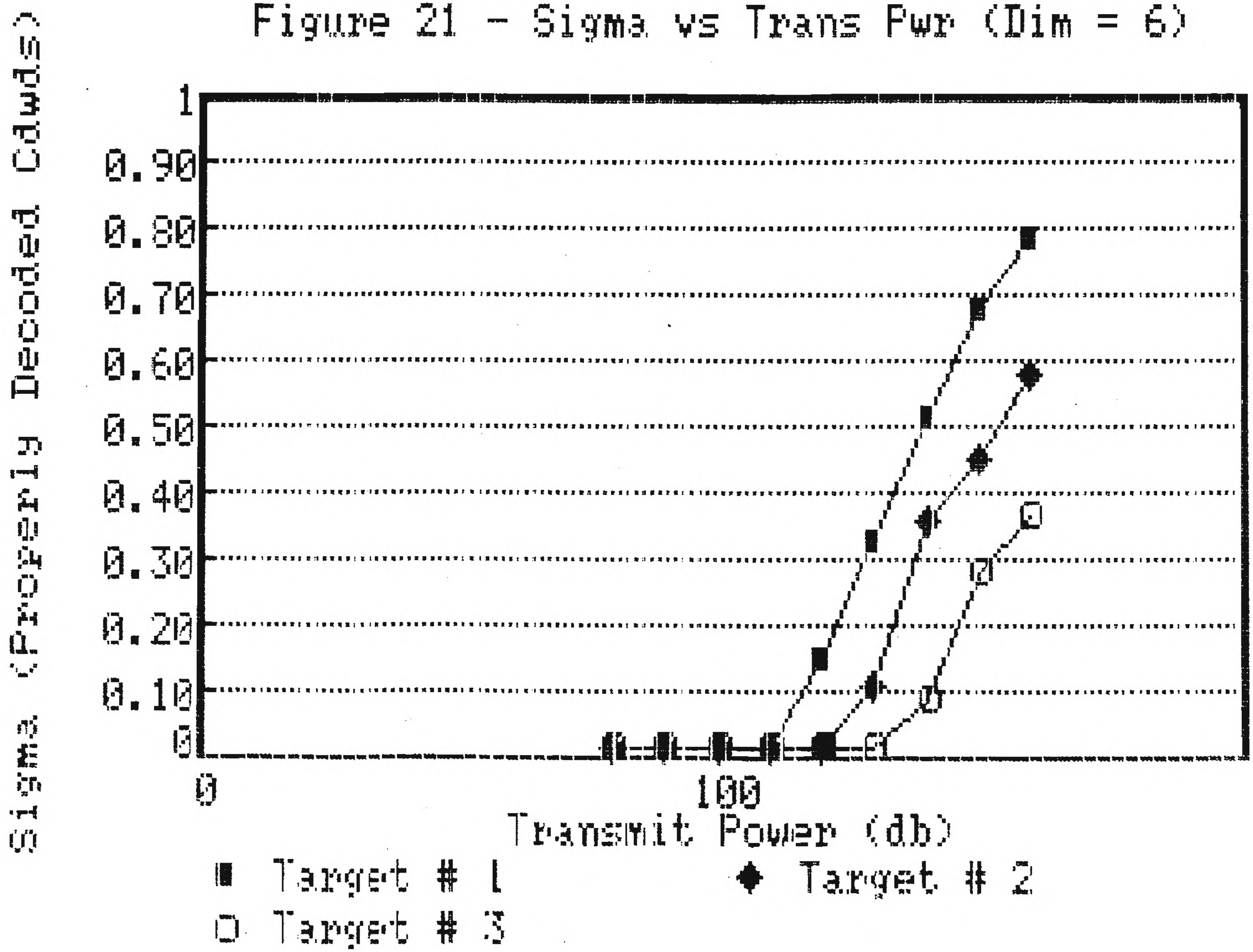


Figure 22 - Sigma vs Trans Pwr (Dim = 7)

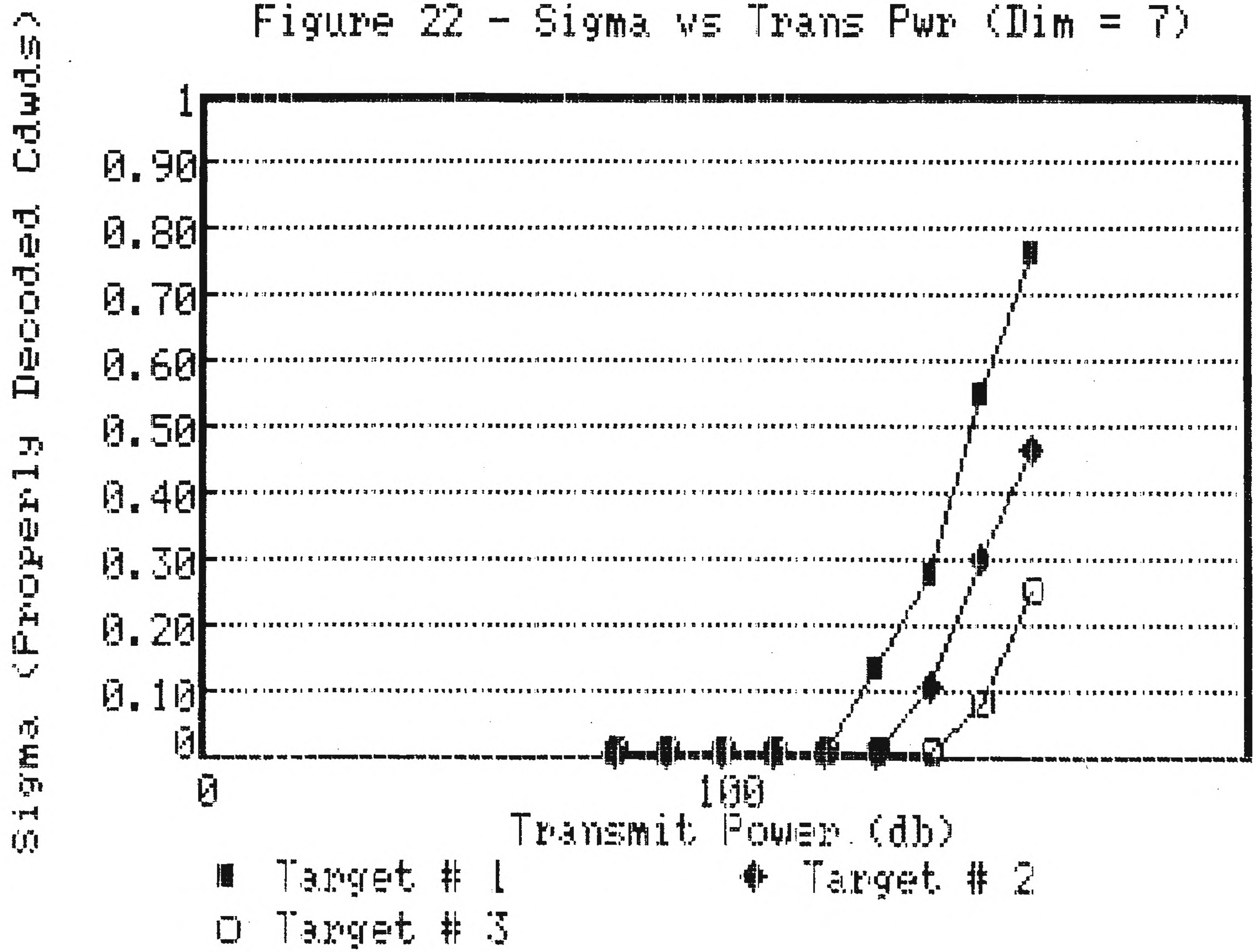
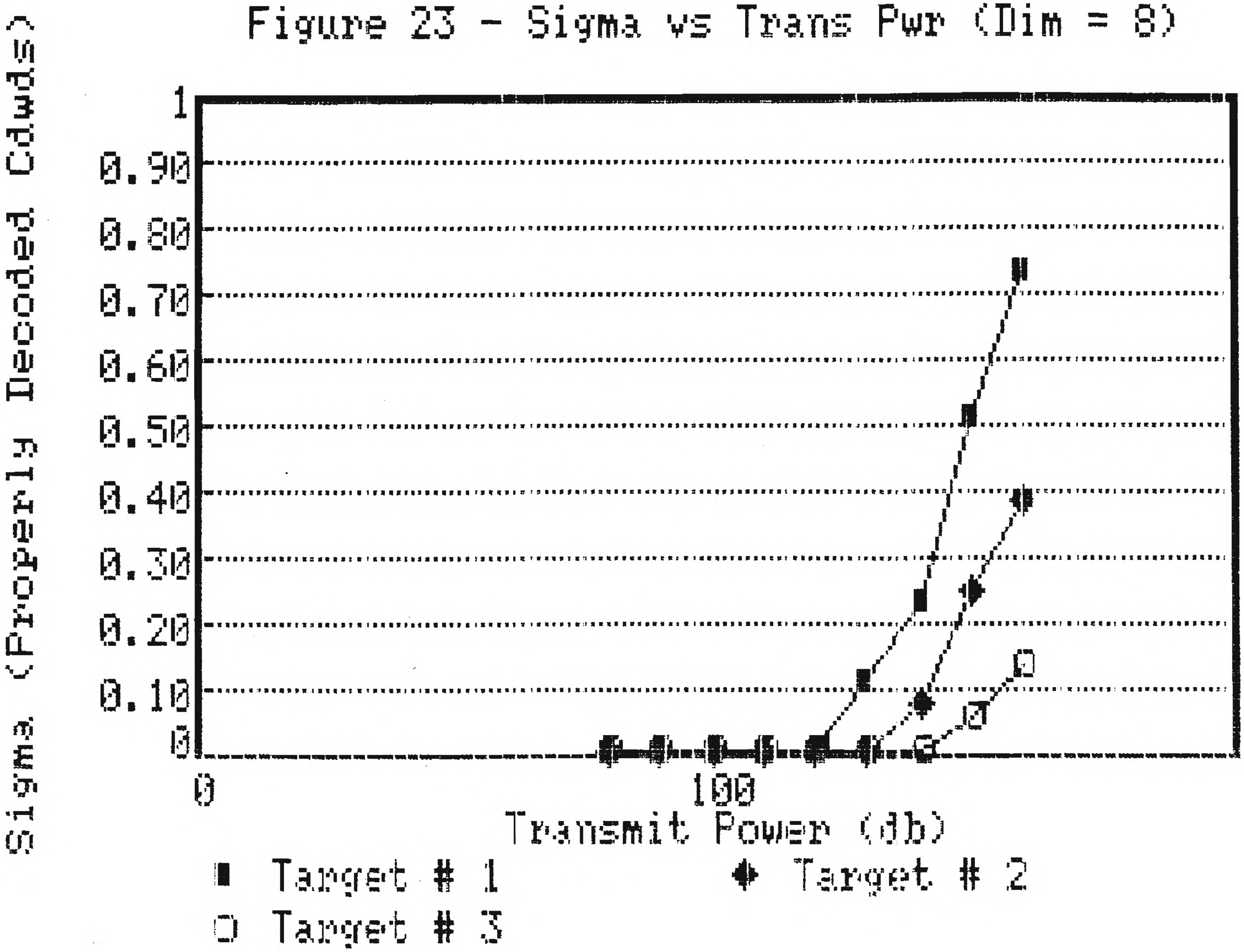


Figure 23 - Sigma vs Trans Pwr (Dim = 8)



ii) The system degradation occurs in a non-linear threshold manner. i.e., sigma falls off rapidly below some power threshold. The value at which sigma falls off is target strength and distance dependent. However, if high enough signal power is used, all targets can be detected with an acceptably high sigma value.

iii) The transmission power at the targets is substantially higher than the sea-state noise. However, as discussed earlier, this additional power looks like increased sea-state noise and therefore not as easily detected as a narrow band sonar signal. i.e., the CSVQ signal increases the environment from sea-state 1 to sea-state 4 (in one case).

The disadvantage of the above results is that although the CSVQ signal looks like environmental noise, it is very directional. This suggests that future research should look at generating CVSQ codebooks based on directional sources such as rain or biological life. This issue will be revisited later.

Computational Load for CVSQ system

The amount of computations for this system is dependent upon the dimension size used. The figure of merit used for computational estimates is the number of multiplies needed per second. This value increases geometrically as dimension size increases. A worst case estimate occurs with dimension size equal to 8. Using dimension equal to 8 the following multiplications are needed:

Decoding

-

2**8 times 8 Multiplies for each 8 samples
(This occurs for each strength/distance calculation)

= 300 million multiplies per second
(using fs = 40 k)

Several reduction techniques can be used to minimize the computational load. Binary search methods can yield a VQ decoding process which uses log(256) instead of 256 comparisons. Also using a distance resolution of more than 1/20 meters per sample would reduce the load. For example, using a resolution of 10 meters per sample and a binary tree search for decoding would yield a computational load of:

computational load (using reduction
techniques) = 50,000 multiplies per second,

which is well within the realizability of digital processing systems.

The computational need for transmission and codebook design are both well below the above values. As with the case with many coding systems, the decoding portion dominates the computational load of the system.

5. CONCLUSIONS AND FUTURE RESEARCH

The major result of this research is that the CSVQ system performs well in an multi target environment. The simulation results show a proof of concept. However, there are some improvements that could enhance the simulation models. Some improvements are as outlined:

i) More accurate target reflection models
   - the targets were assumed to be point sources which greatly simplified the sonar reflection calculations. Some improvements in the model could include such parameters as angle of reflection, spread reflection instead of point reflection, and non-linear sound propagation.

ii) Determine the performance of the CVSQ system with other training sequences. Some immediate candidates for CSVQ signal set design are marine life (whales, squid, shrimp), rain, etc.

All these sources have the advantageous property of being directive signals.

iii) Preliminary sea tests could be done to verify and enhance the simulation models used. Small sea tests could take place for a single target of a non-classified nature.

iv) The CSVQ system was initially proposed as an covert communications system [15]. It would be interesting to simulated the CSVQ system for this purpose. Some preliminary indications show increased performance due to the one-way transmission loss instead of a two-way loss.

Concerning future research, the author wishes to present some improvements in the ability to conduct research at Tuskegee University. These improvements would either enhance the computing facility or the personnel support for conducting this research. The suggested improvement areas are as follows:

i) Increase the hard-disk memory on the Micro VAX.
   - Presently, the hard disk memory residing on the Micro VAX is 70 MBytes. This amount is drastically insufficient due to the storage requirements of the algorithms. An increase of hard disk memory to 400 - 500 MBytes should eliminate any memory deficiencies.

ii) Research Assistant and Graduate Support

- Due to the immense magnitude of this work, full-time assistant and graduate student aid would greatly reduce the work load for the principle investigator. The appropriate level of support should be one full time assistant and one graduate student.

An estimate on the cost for continuing this research including the above enhancements is $70,000 (for the next year). A detailed proposal and cost breakdown can be supplied upon request.

Acknowledgements

The author would like to thank the Naval Coastal Systems Center for its cooperation and support in granting Tuskegee University the opportunity to pursue this research effort. As with the nature of research, there was an immense amount of knowledge learned from this effort. The author desires that this grant is only the beginning of a long and fruitful relationship between our two organizations.

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APPENDIX A - Numerical Example of an VQ Coding Process

For this example we will use the following parameters:

Dimension Size = 3
Codebook Size = 5
Input Signal Length = 12

X - Input Signal (Sequence of 12 Numbers)
5.2, 7.8, 15.9, 40.3, 67.8, 30.6, 10.2, -30.8, -60.9, -70.2, -30.4, -13.1

C - Codebook (Consisting of 5 - 3 Dimensional Numbers) (Codebook was previously designed.)

c1 - -12., -30., -45.
c2 - 4.3, 2.8., 10.
c3 - 4.4, 3.0, 11.
c4 - 30., 42., 42.
c5 - -75., 42.3, 39.

Step 1) Block Input Sequence into 3 Dimensional Vectors:

From the above sequence X,

x1 - 5.2, 7.8, 15.9
x2 - 40.3, 67.8, 30.6
x3 - 10.2, -30.8, -60.9
x4 - -70.2, -30.4, -13.1

Step 2) Match the Input Vectors to their closest Codewords using a mean-squared error (euclidean) distortion measure:

x1 --> c3
x2 --> c4
x3 --> c1
x4 --> c1

Step 3) Generate a reproduction sequence Y from the sequence of encoded codewords:

Y - reproduction sequence
- c3, c4, c1, c1
- -4.4, 3.0, 11., 30., 42., 42., -12., -30., -45., -12., -30., -45.

APPENDIX B - Numerical Example of an VQ Codebook Design

For this example we will use the following parameters:

Dimension Size = 2
Codebook Size = 2
Original Signal Length = 8

X - Input Signal (Sequence of 8 Numbers)
10., 12., 9., 11., -5., -4., -3., -6.

C - Original Codebook (Consisting of 2 - 2 Dimension Numbers)

c1 - .001, .001
c2 - -.001, -.001

Step 1) Block Input Sequence into 2 Dimensional Vectors:

From the above sequence X,

x1 - 10., 12.
x2 - 9., 11.,
x3 - -5., -4.,
x4 - -3., -6.,

Step 2) Match the Input Vectors to their closest Codewords using a mean-squared error (euclidean) distortion measure:

	Distortion Between Mappings
x1 --> c1	244
x2 --> c1	202
x3 --> c2	41
x4 --> c2	45
Total Distortion	532

Step 3) Generate New Codebook by averaging the input vectors which mapped to it:

c1 = (x1+x2)/2
c2 = (x3+x4)/2

c1 - 9.5, 11.5
c2 - -4., -5.

Step 4) Repeat Step 2) with new codebook:

Distortion Between Mappings

```
        x1 --> c1              .5
        x2 --> c1              .5
        x3 --> c2              2.0
        x4 --> c2              2.0

        Total Distortion       5.0

 Step 5) Repeat Step 3) with the new mappings:
         (In this case, the mappings are the same.)

        c1 = (x1+x2)/2
        c2 = (x3+x4)/2

        c1 - 9.5, 11.5
        c2 - -4., -5.

Step 6) Repeat Step 2) with the new codebook:
        (In this case, the codebook is the same)

                      Distortion Between Mappings
        x1 --> c1              .5
        x2 --> c1              .5
        x3 --> c2              2.0
        x4 --> c2              2.0

        Total Distortion       5.0

 Step 7) Continue iterating between Steps 2) and 3)
         until the decrease in total distortion of
         step 2) stops. (In this case, only two
         iterations were needed.)

        C - Final Codebook

        c1 - 9.5, 11.5
        c2 - -4., -5.
```

This value represents Pfa.

A few points can be discussed about the above equations. First, both Pd and Pfa are inversely proportional to sigth. This is true since the possible combinations of obtaining sigth*L codewords decrease as sigth rises. Both Pfa and Pd can be calculated and plotted as a function of sigth.

Secondly, the above calculations depend on the knowing the values of pdvt and pdvn. Both these values depend on signal strength, target distance, and target strength. However, pdvt and pdvn can be determined experimentally using the CSVQ simulation programs of this research.

APPENDIX C - Determination of Pfa and Pd for the CSVQ System

Since the CSVQ system attempts to decode the original sequence of codewords, there is an inherent relationship between the amount of correctly decodable codewords, probability of false alarm - Pfa, and probability of detection Pd. Defining the following terms:

pdvt - probability of the ith codeword being decoded properly in a target environment.

pdvn - probability of the ith codeword being decoded non properly in a no target environment.

sigma - ratio of correctly decoded codewords to total number of codewords in window
0 <= sigma <= 1

L - window size for sigma computation

sigth - threshold value used to determine whether a target is present
0 <= sigth <= 1

Then the following statements can be made.

i) Given pdvt, the probability of obtaining sigma*L properly decoded codewords in an environment with targets is:

$$\sum_{K=SIGTH\cdot L}^{L} \binom{L}{K} Pdvt^{K} (1-Pdvt)^{L-K}$$

This value represent Pd.

ii) Given pdvn, the probability of obtaining sigth*L non-properly decoded codewords in an environment with no targets is:

$$\sum_{K=SIGTH\cdot L}^{L} \binom{L}{K} Pdvn^{K} (1-Pdvn)^{L-K}$$

APPENDIX D - Program Listing for CSVQ System

Program	Purpose
Rand.f	Generate Random Number Sequence for White Gaussian Noise Source
Bpf.f	Filter Noise Sequence to Specified Frequency Bands
Trans.f	Filter Transmit and Receive Signal Through Transducer Response
Sbrev.f	Calculates Surface/Bottom Reverberation Values
Volrev.f	Calculates Volume Reverberation Values
Modvq.f	Calculates VQ Set Using Noise Sequence as Training Samples
Modvq1.f	Same as Modvq.f, but uses a Different Codeword Generation Technique to Enable Maximum Separation of Codewords
Modvq2.f	Same as Modvq.f, but uses a Different an Absolute Value Distortion Measure Instead of Euclidean Distance
Trmit.f	Transmits VQ Signal Set into Volume
Recv.f	Receive Reverberation Plus Target Echo Plus Noise
Target.f	Calculates Target Echoe Values for Recv.f
Norm.f	Normalizes Returned Signal
Decode.f	Decodes Normalized Signal using VQ Codebook
Sigma.f	Calculates Sigma Value for Decoded Codebook
Param.f	Generates Experiment Simulation Parameters
Tstdec.f	Tests Decode.f Under a No-Noise Environment

Tsttar.f	Tests Decode.f Under a No-Target Environment
Tstcod.f	Tests Decode.f Under a No-Codebook Environment