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מוסד הטכניון למחקר ופיתוח בע"מ
TECHNION RESEARCH & DEVELOPMENT FOUNDATION LTD.

EORD
היחידה למחקר ופיתוח אלקטרואופטי
ELECTRO - OPTICS RESEARCH & DEVELOPMENT UNIT

ACOUSTIC SOUNDING SYSTEM FOR LONG RANGE PROPAGATION IN MIDDLE EAST SURROUNDINGS

Third Interm Report

Item 003

July 1995

Report No.: 5875/845

טכנולוגיות חישה מתקדמות, אלקטרו-אופטיקה, אקוסטיקה, גמ"מ
ADVANCED SENSING TECHNIQUES, ELECTRO-OPTICS, ACOUSTICS, MMW

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13.ABSTRACT(MAXIMUM 200 WORDS) The current report covers the activities carried out during the third interim period. Two main tasks were performed namely a preliminary open air acoustic transmission experiment and a computer simulation of atmospheric acoustic propagation based on an FPP program. The measurements were performed using the complete DAS system consisting of a 6 horn APS and the ADRA receiver unit located at a distance of 800m from it. The source was operated at discrete frequencies of 150,300,450,600,1000 and 1200Hz. The angles of arrival of the acoustic energy over two second intervals were determined. It was found that the lower frequencies (300,450,600Hz) tended to arrive in directions closer to the ground whereas the energy from higher frequencies (1000,1200 Hz) tended to come from directions higher up in the atmosphere. Experimental results and model calculations for a typical atmospheric sound speed profile are included.			
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Title Page

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2. Name of Principal Investigator : Dr.Z.Zlotnik, Dr.L.B.Salem

3. Name of Contractor : EORD, Technion, Haifa, ISRAEL.

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Third Interim Report

This report briefly describes the design and field measurement activities carried out during the third interim period. The report includes results obtained from a field test involving the complete DAS system with the 6-horn source and the the directive acoustic antenna.

1. The Acoustic Power Source -APS

1.1 Following an analysis of the acoustic radiation pattern formed by different configurations of the 3-horn source it was found that an air spacing of 20cm at the individual horn ends yielded the desired beam with regards to effective radiation power and beam width. No appreciable advantage was obtained by inserting different material screens in between the horns

1.2 The 6-horn linear array was configured with a 20cm air spacing at the individual horn ends. To each horn was attached a single driver unit. Two acoustic drivers were powered from a single power amplifier unit. The three separate amplifier units were fed from a single function generator thereby achieving phase matched outputs from the individual horns. This was experimentally determined by two different methods one using a Lock-in -amplifier and the other using a digital oscilloscope. For these measurements a single microphone was positioned at a distance of 2m in front of a horn and the phase determined with respect to that of the function generator source.

1.3 The linear array was divided into two groups of three each and each group was mounted on a rail of 2.5m in length. Each rail was mounted on a Quickset head that was capable of both pan and tilt motions. This arrangement allowed one to mechanically scan the generated acoustic beam through an azimuth angle of 0° to 300° and an elevation angle of -30° to 60°.

2 Preliminary Acoustic Transmission Experiment using The Directive Acoustic Sounding System(DAS)

2.1 The Acoustic Power Source(APS) and the Acoustic Directive Receiver Antenna(ADRA) together form the DAS unit. A preliminary open air acoustic transmission experiment was carried out on 22/5/95 under daytime conditions.The experimental setup under which the measurements were performed is described in the following sections..

2.2 The DAS source and receiver units were setup in an open field at a distance of 800m apart. A team of two operated the APS and a second team of two the ADRA. The circular array of microphones of the ADRA was positioned such that the reference microphone from which azimuth angles were determined pointed towards the source.

2.3 The APS was operated in a continous wave(CW) mode using a sinusoidal wave input.The frequencies of transmission were chosen to be at 150,300,450,600,1000 and 1200 Hz respectively.
The frequencies were transmitted one at a time and the period of the experiment was about an hour.
The APS was operated at two elevation angles,one at 0°(Zenith angle=90°) and the other at 30°(Zenith angle=60°).
The APS height was 1.5m above the ground.

2.4 At the ADRA end the microphone signals from 16 channels were recorded by a dedicated software program. The signals were recorded continously for a period of 30sec for each event. The beam-forming program then divided this recording to segments of 2sec(giving a 0.5Hz resolution based on 4096 digitized samples). For each segment both the azimuthal and zenith angles were determined.
The circular array microphones were at a height of 0.95m above the ground.

3. Results

3.1 The microphone measurements were analyzed to yield signal levels at the transmitted frequency by performing a FFT analysis.

3.2 The frequencies were transmitted sequentially. In all cases the received signal intensity fluctuated over the recording period of 30sec even though the source signal was maintained at a constant amplitude.The intensity swing was around 10-15dB.

3.2 A beam forming alogrithm was employed to yield both azimuth and elevation angles of the incident acoustic beam.on the microphone array. In all the cases it was found that the azimuthal direction of the recorded acoustic beam corresponded to the source location(Azimuth angle=0°).

3.3 The zenith angle was found to vary as a function of frequency. It was found that at the lower frequencies(300,450 and 600 Hz) the acoustic energy arrived most of the time over a band of zenith angles between 70° and 90°.At the higher frequencies (1000 and 1200 Hz) the zenith angles were found to lie roughly in two groups. In one group the arrival zenith angle was between 30° and 50° and the other group between 80° and 90°
The zenith angles at 150 Hz were found to vary over a wide range of angles. A possible reason for this could be the sensitivity of the beam forming algorithm to the physical parameters of the antenna. The antenna was configured to have a diameter of 2m and hence its performance is expected to be good from around 300Hz and above.

3.4 The dependence of the arrival zenith angle on the initial source zenith angle(90° and 60°) was not evident. This result can be explained by considering the beam width of the APS which is the same as that of an individual horn (60°) in the zenith direction.

3.5 The zenith angles of arrival and typical signal strengths are given as a series of graphs in Appedix 1. In the graph title the term s-h/a stands for source height and source elevation angle The term r-h corresponds to the height of the circular array of the ADRA.

3.6 The air and wind profiles (to a height of at least several hundred meters) of the atmosphere at the experimental site were not available.However at the source end the air temperatures at heights of 5,10,20,50 100,150 and 200cm above the ground were measured during the duration of the experiment. Local wind velocity at a height of 2m was also measured. These measurements are also included in the appendix.

4. Acoustic Propagation Model in the Atmosphere

4.1 In addition to the experimental measurements acoustic propagation calculations were performed using an FPP program.The program was run using atmospheric sound speed profiles as given in an ARL paper .("The importance of ducting in atmospheric acoustics" by J.M.Noble, BED,U.S.Army Research Laboratory,White Sands Missile Range,New Mexico 88002-5501). The results obtained from the FPP up to a horizontal range of 5000m and for frequencies of 100,200,300,and 600Hz are given in Appendix 2.

4.2 Several graphs of normalized pressure versus range are obtained . The graphs vary from each other in the Sound Speed Distribution(SSD) employed for the calculation. The sound speed versus height distribution is included along with the pressure.-range graphs

4.3 From the calculations we see that there is a rapid fall of the pressure up to a distance of around 500m and then much more gradually. There is fall of approximately 50 dB at a distance of 1000m. This more or less agrees with our experimental results. However a better comparison with the model requires an actual atmospheric sound speed profile at the experimental site.

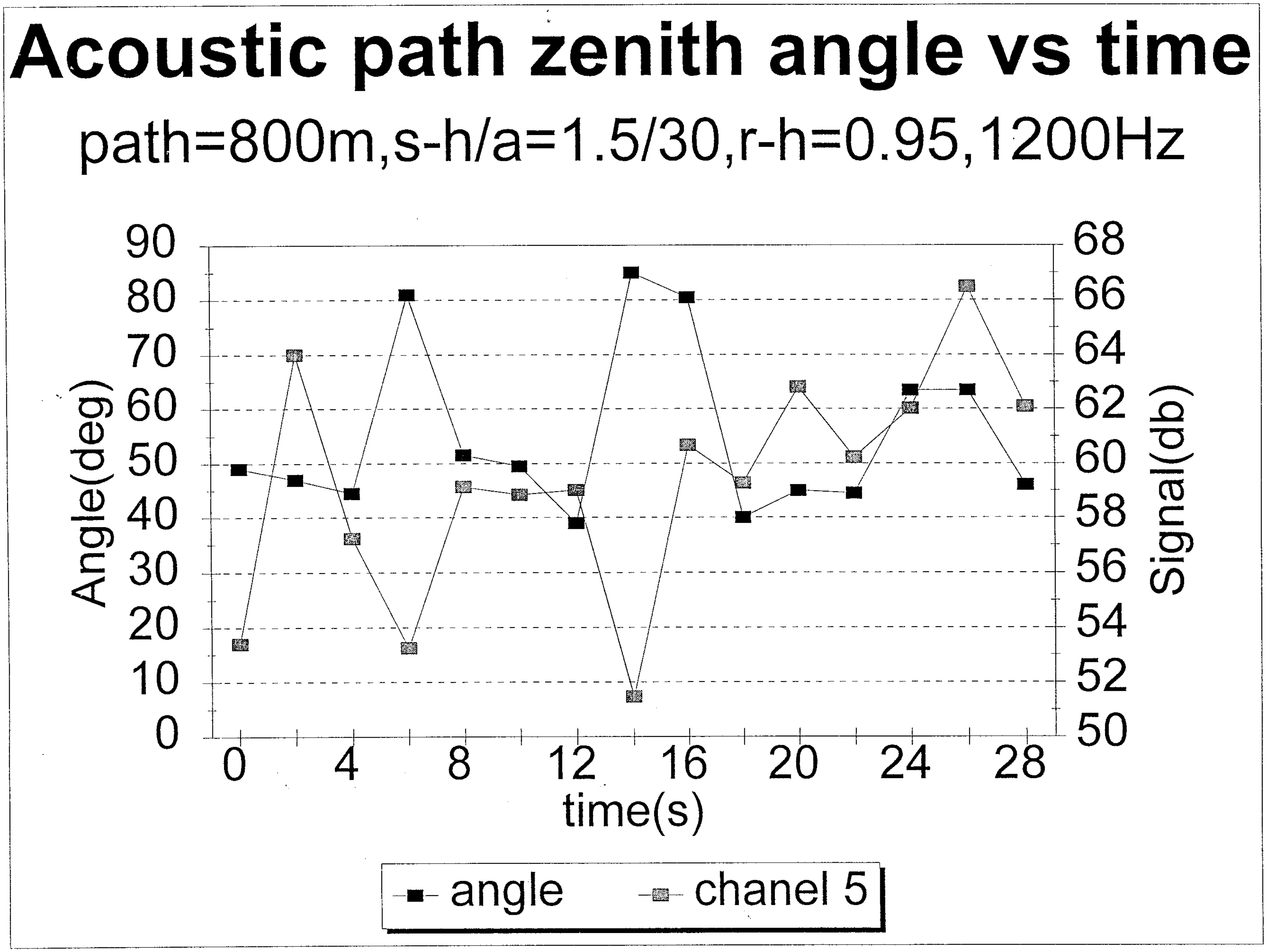
5. The next stages of the research

5.1 Carrying out open air transmission measurements at a site where local SODAR measurements are available.

5.2 Carrying out experiments where the source is operated in a BURST mode followed by Time Domain analysis of the recorded signals.

5.3 Modifying the FPP to give signal strengths as a function of acoustic ray paths from source to receiver.

Appendix 1


Acoustic path zenith angle vs time
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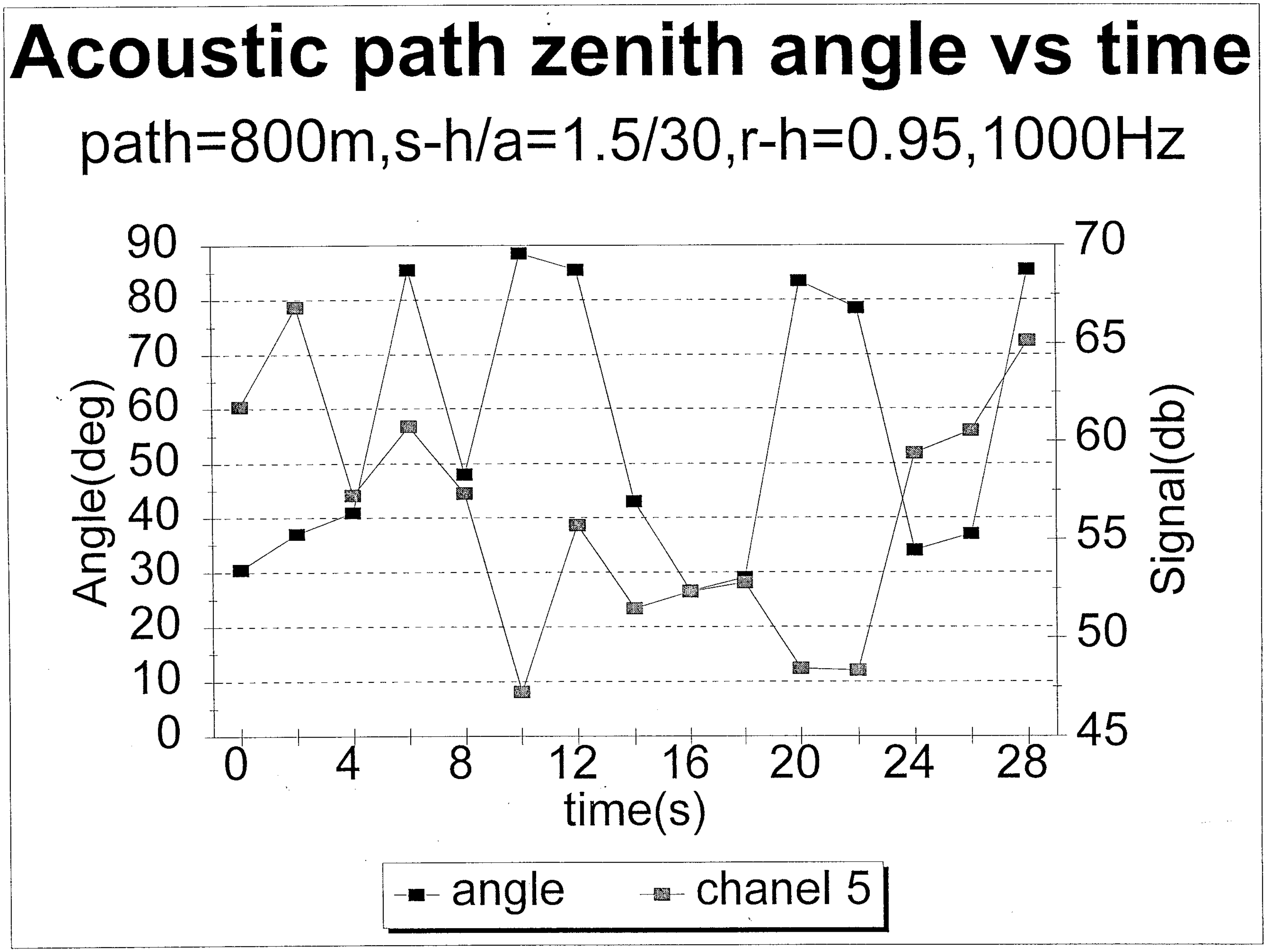
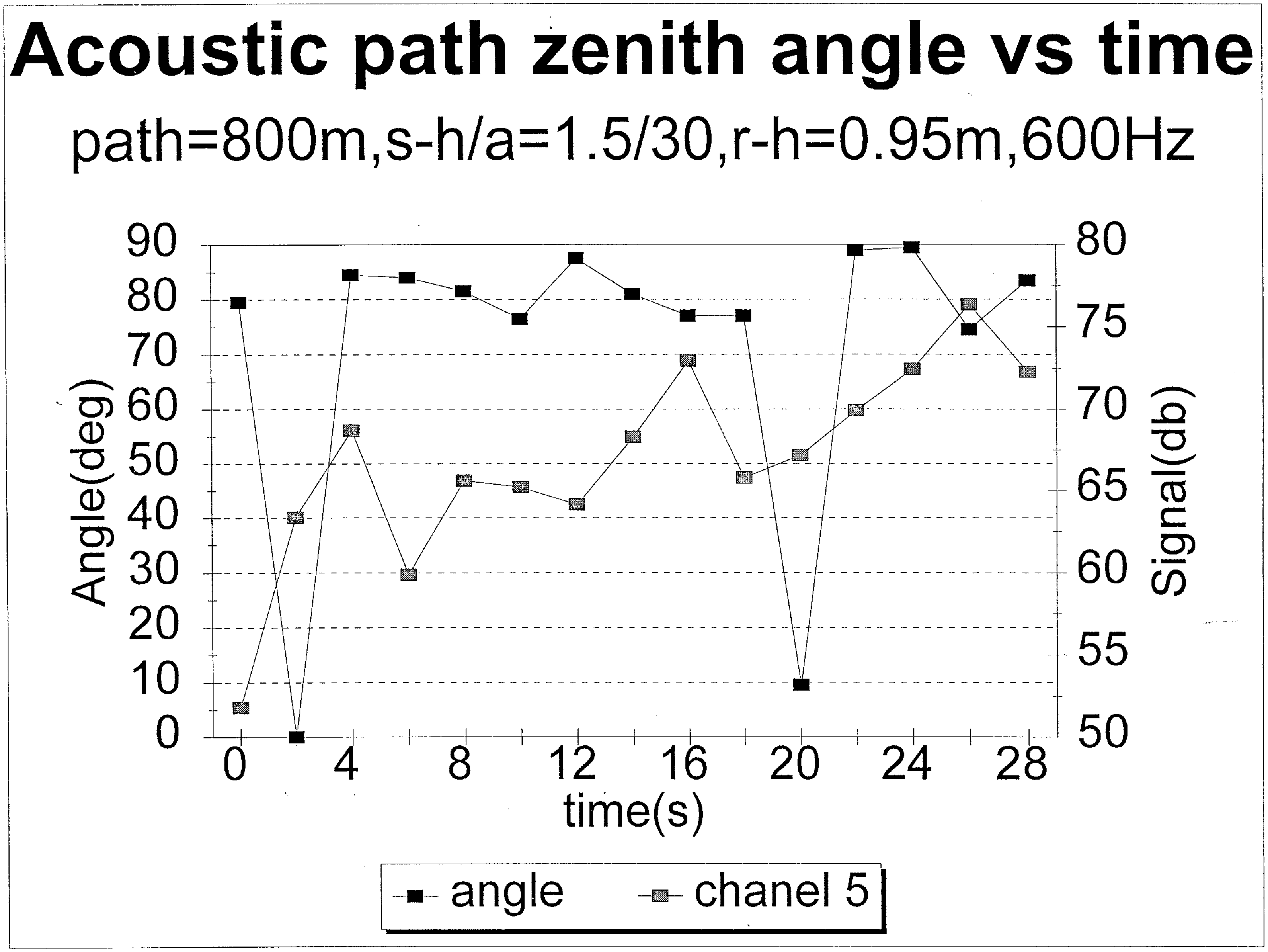
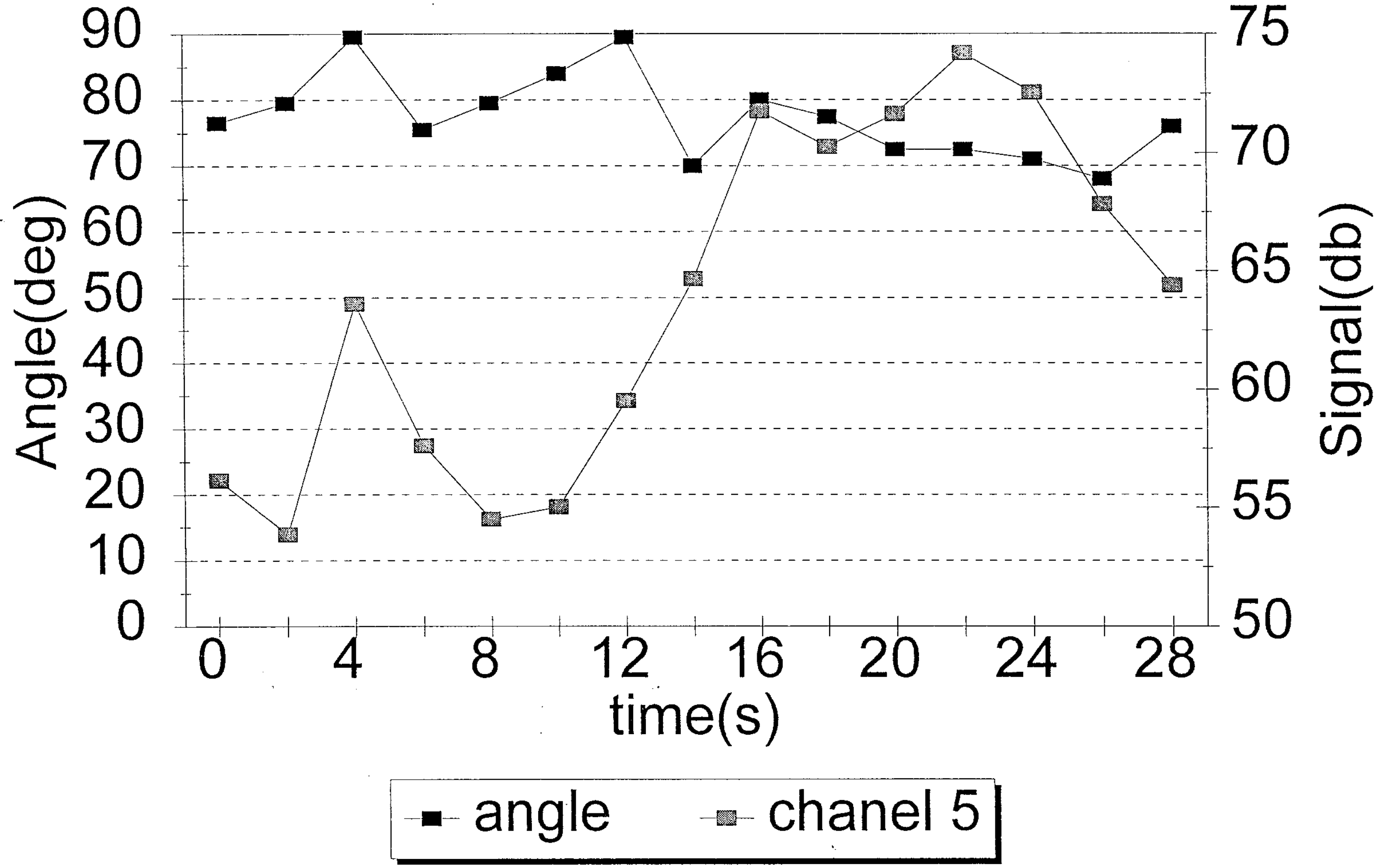
90
80
70
60
50
40
30
20
10
0
Angle(deg)
68
66
64
62
60
58
56
54
52
50
Signal(db)
0
4
8
12
16
20
24
28
time(s)
angle
chanel 5

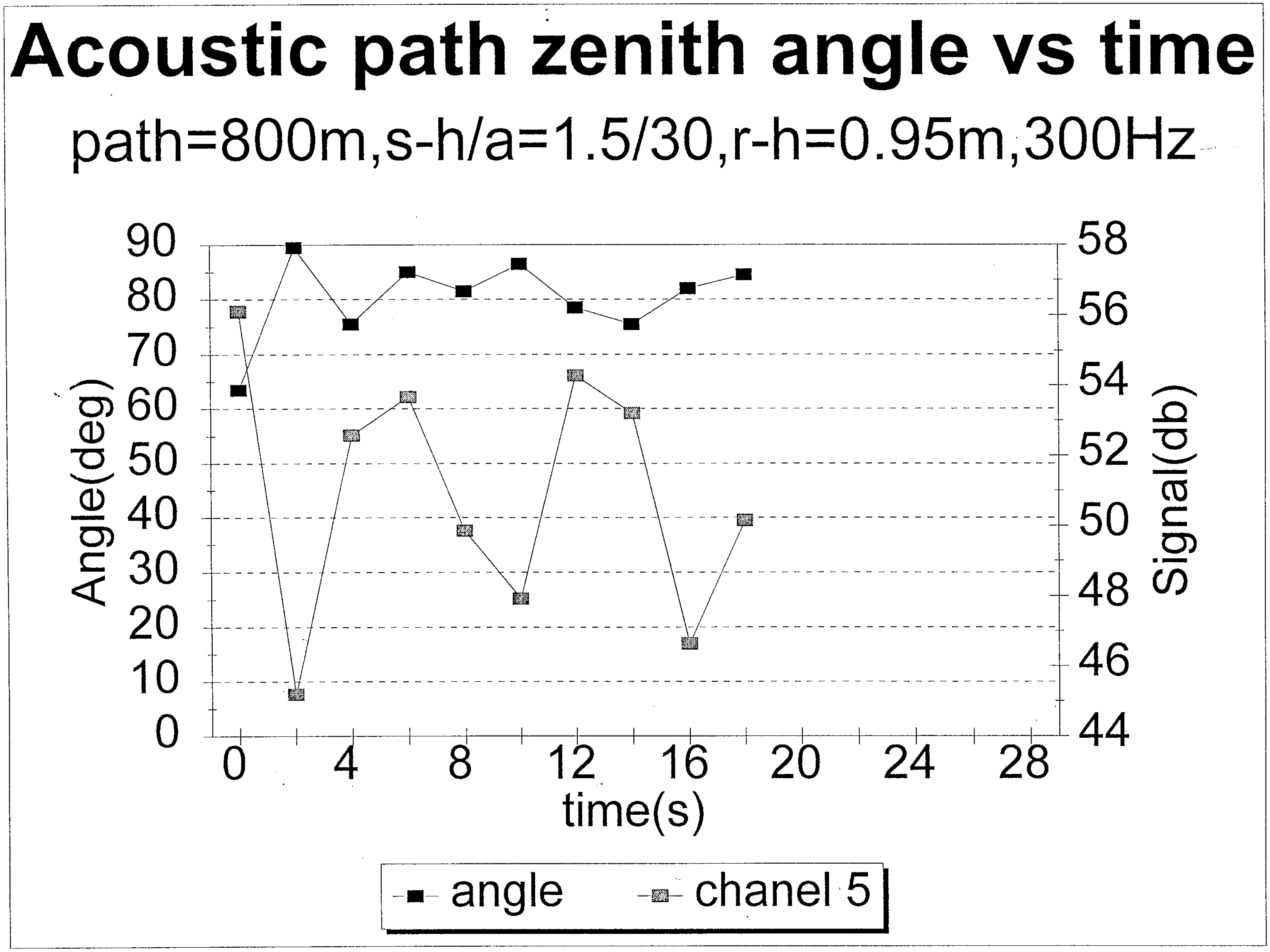

Acoustic path zenith angle vs time
path=800m,s-h/a=1.5/30,r-h=0.95,1000Hz
Angle(deg)
Signal(db)
time(s)
angle
chanel 5

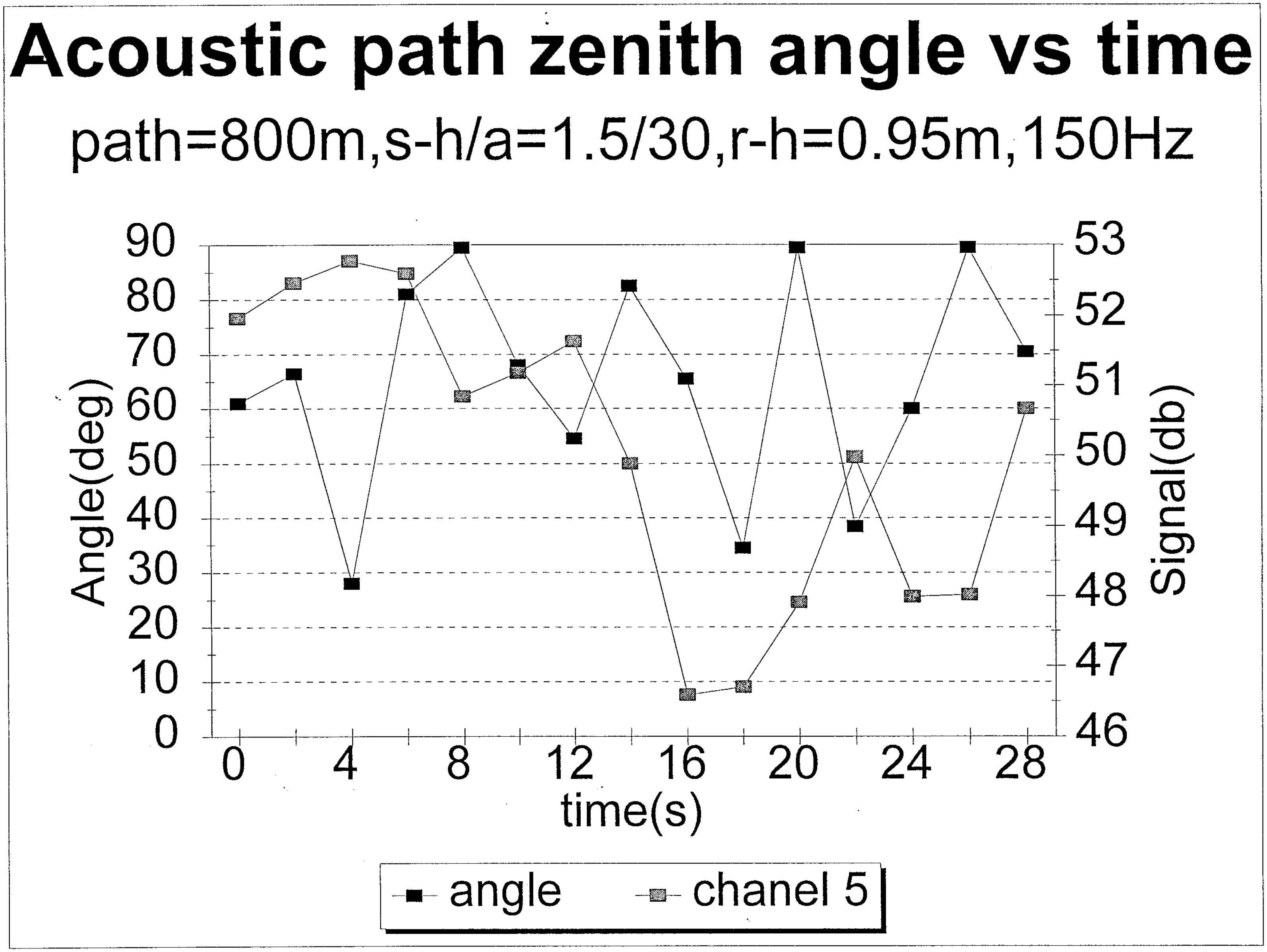

Acoustic path zenith angle vs time
path=800m,s-h/a=1.5/30,r-h=0.95m,600Hz
Angle(deg)
Signal(db)
time(s)
90
80
70
60
50
40
30
20
10
0
80
75
70
65
60
55
50
0
4
8
12
16
20
24
28
angle
chanel 5

Acoustic path zenith angle vs time

path=800m,s-h/a=1.5/30,r-h=0.95m,450Hz




Acoustic path zenith angle vs time
path=800m,s-h/a=1.5/30,r-h=0.95m,300Hz
Angle(deg)
90
80
70
60
50
40
30
20
10
0
Signal(db)
58
56
54
52
50
48
46
44
0
4
8
12
16
20
24
28
time(s)
angle
chanel 5


Acoustic path zenith angle vs time
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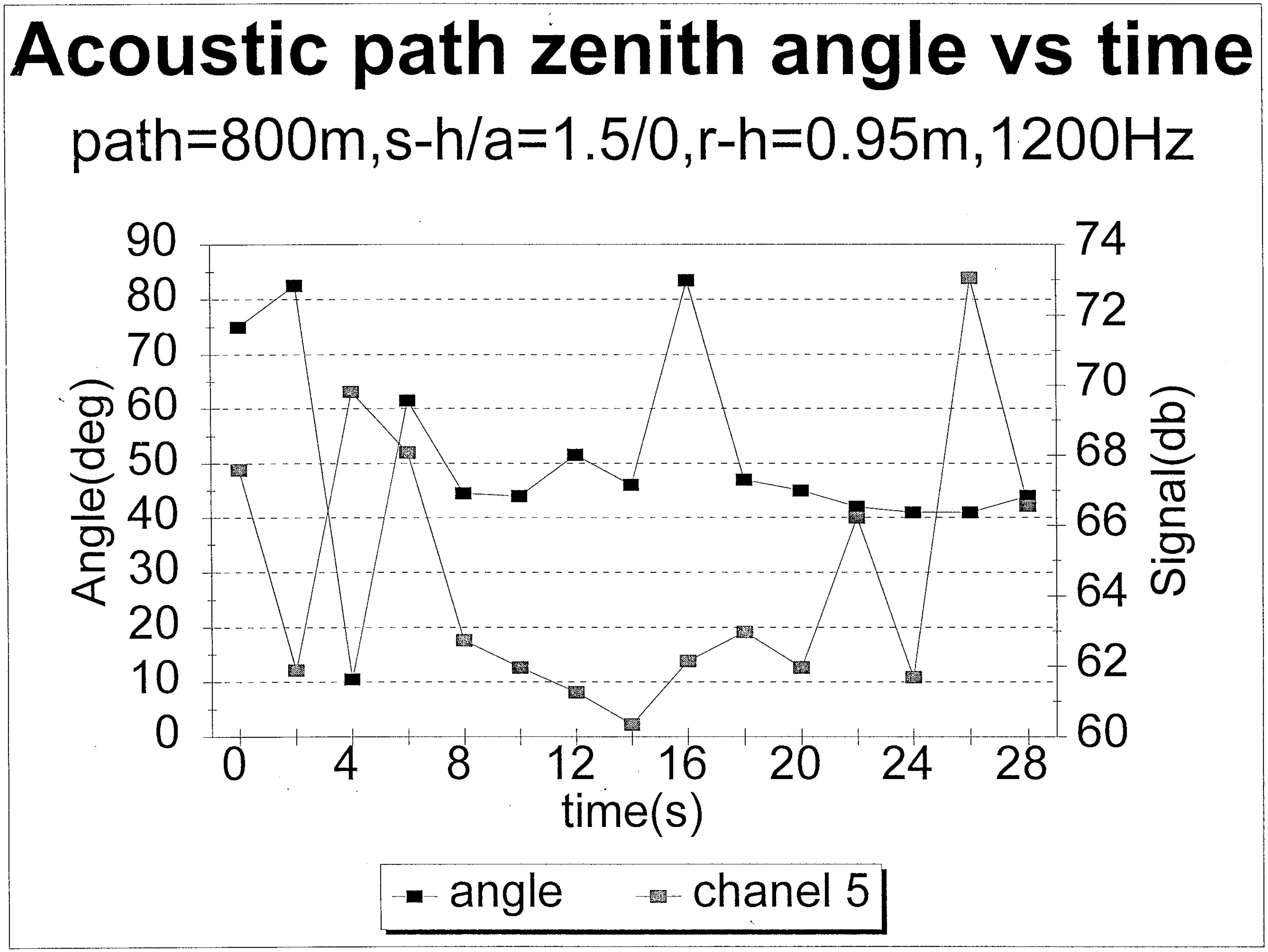
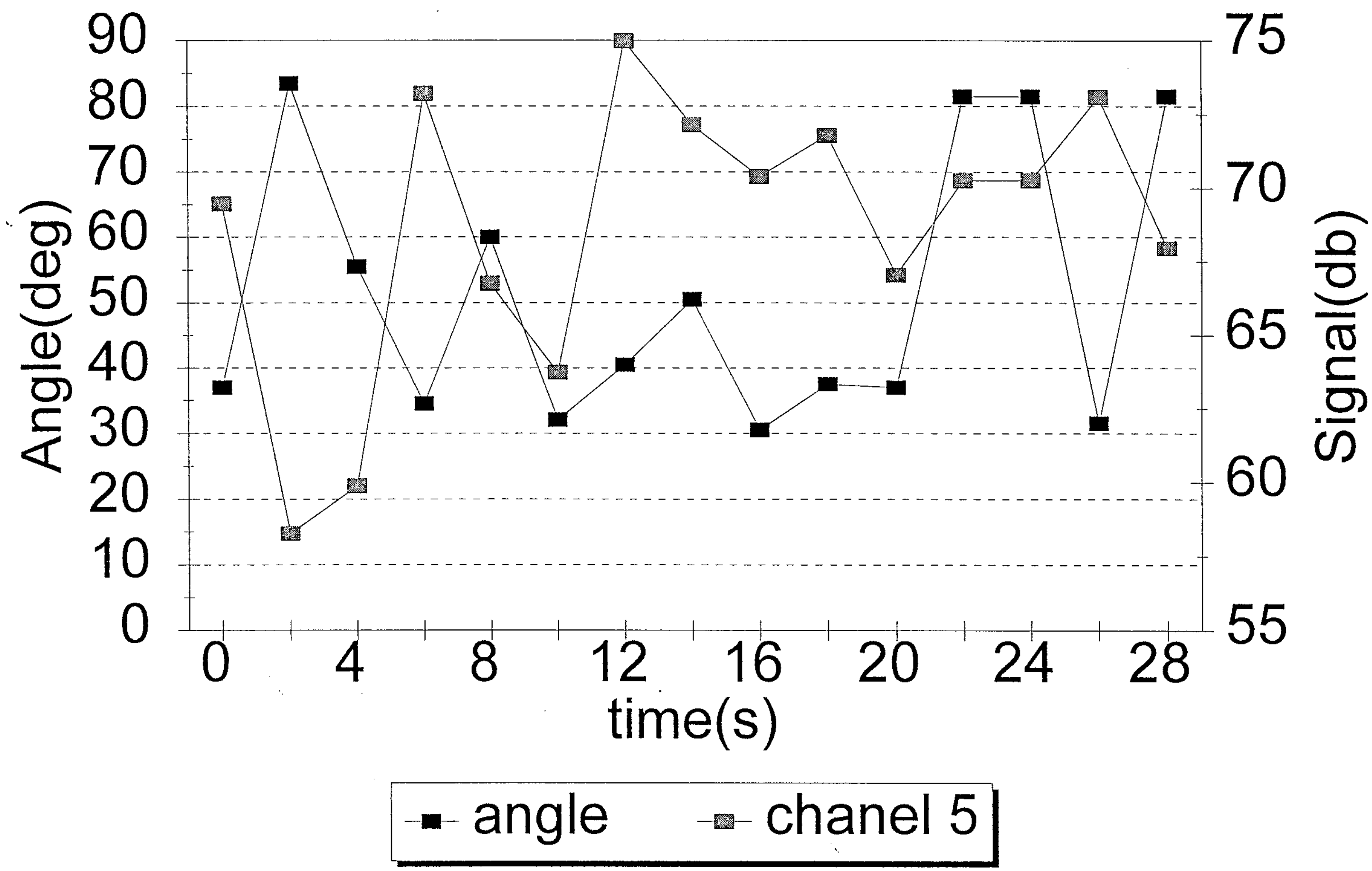
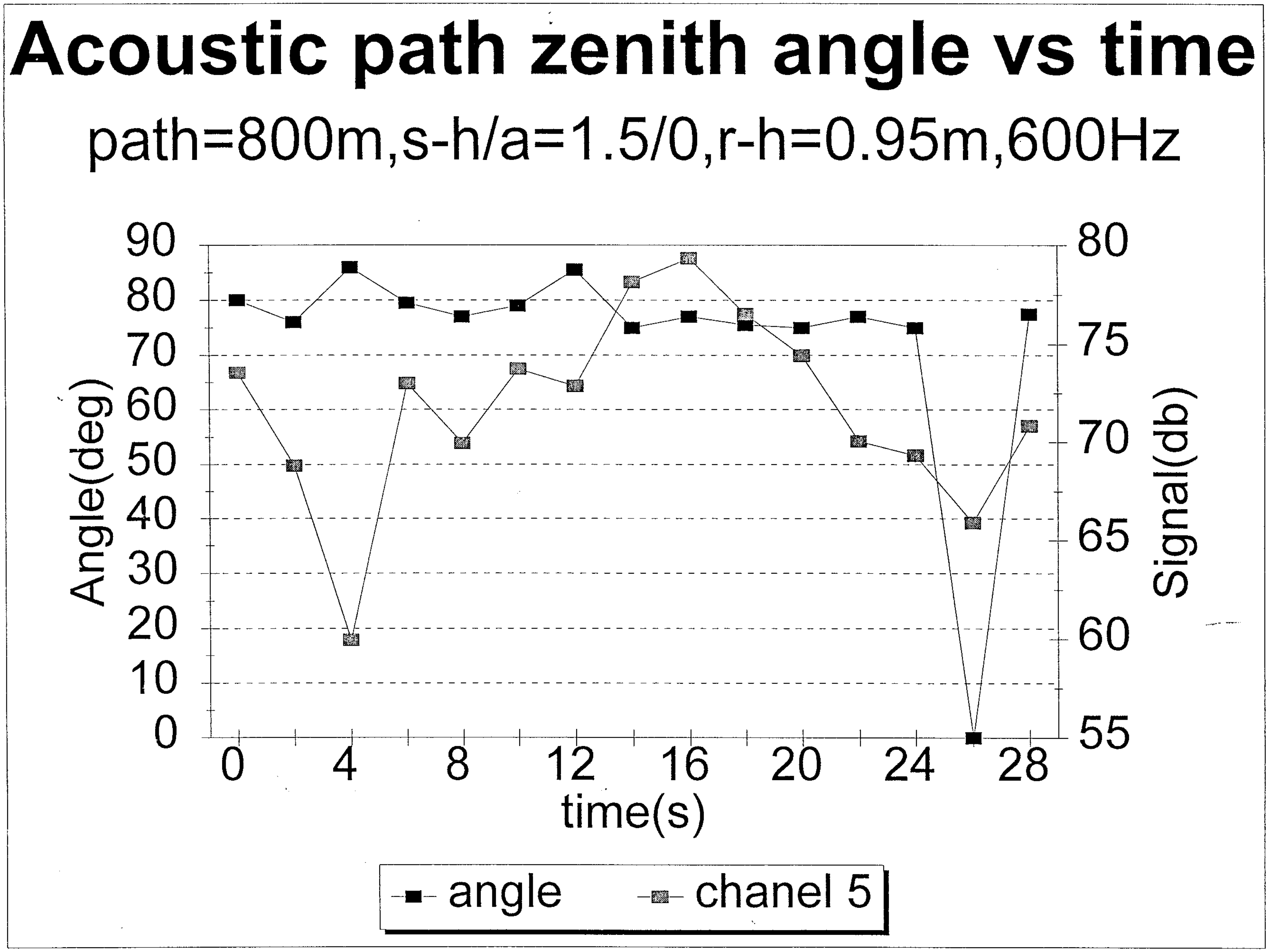
Angle(deg)
90
80
70
60
50
40
30
20
10
0
Signal(db)
53
52
51
50
49
48
47
46
0
4
8
12
16
20
24
28
time(s)
angle
chanel 5


Acoustic path zenith angle vs time
path=800m,s-h/a=1.5/0,r-h=0.95m,1200Hz
Angle(deg)
90
80
70
60
50
40
30
20
10
0
Signal(db)
74
72
70
68
66
64
62
60
0
4
8
12
16
20
24
28
time(s)
angle
chanel 5

Acoustic path zenith angle vs time

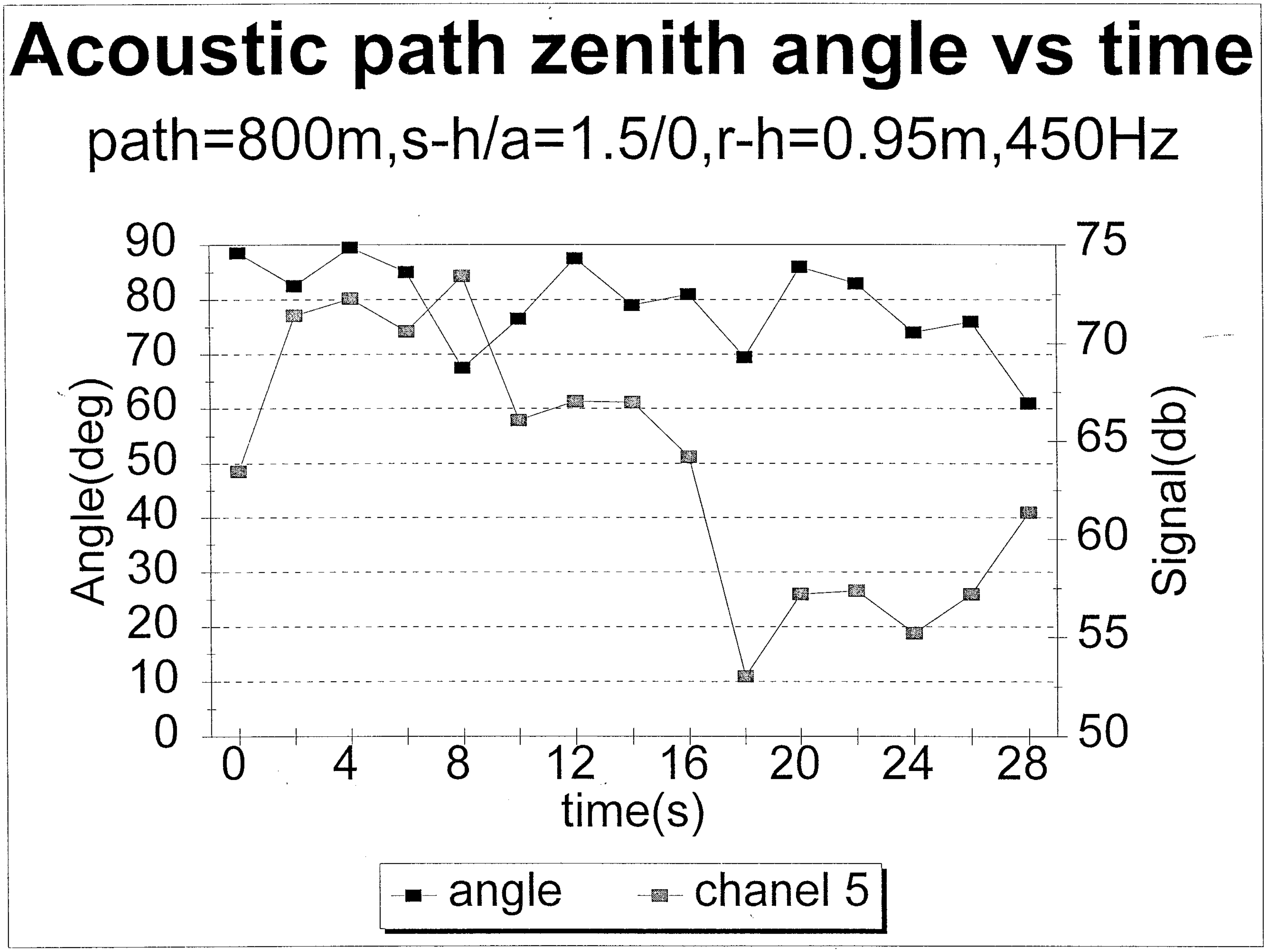
path=800m,s-h/a=1.5/0,r-h=0.95m,1000Hz





Acoustic path zenith angle vs time
path=800m,s-h/a=1.5/0,r-h=0.95m,600Hz
90
80
70
60
50
40
30
20
10
0
Angle(deg)
80
75
70
65
60
55
Signal(db)
0
4
8
12
16
20
24
28
time(s)
angle
chanel 5

16



Acoustic path zenith angle vs time
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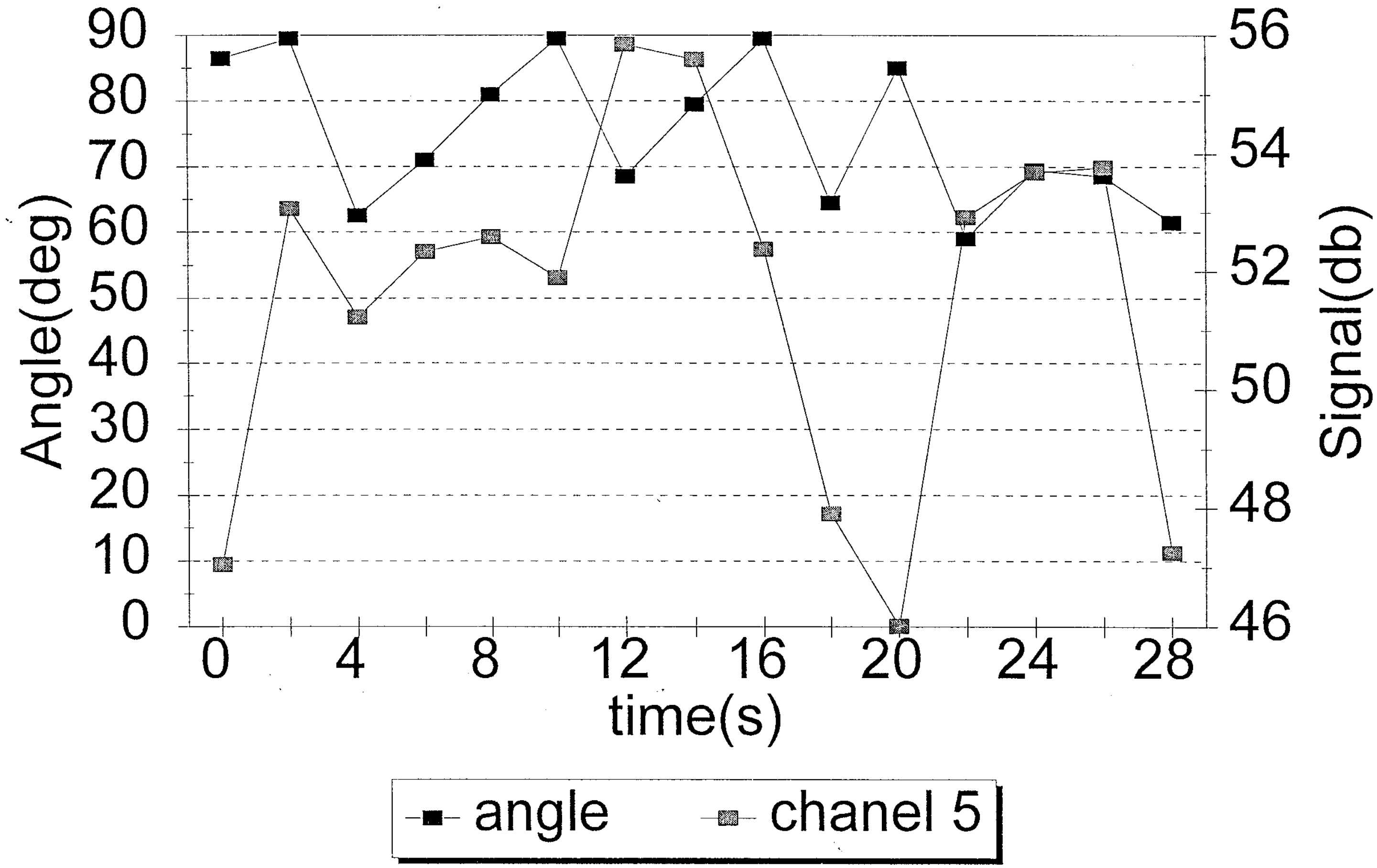
Angle(deg)
90
80
70
60
50
40
30
20
10
0
Signal(db)
75
70
65
60
55
50
0
4
8
12
16
20
24
28
time(s)
angle
chanel 5

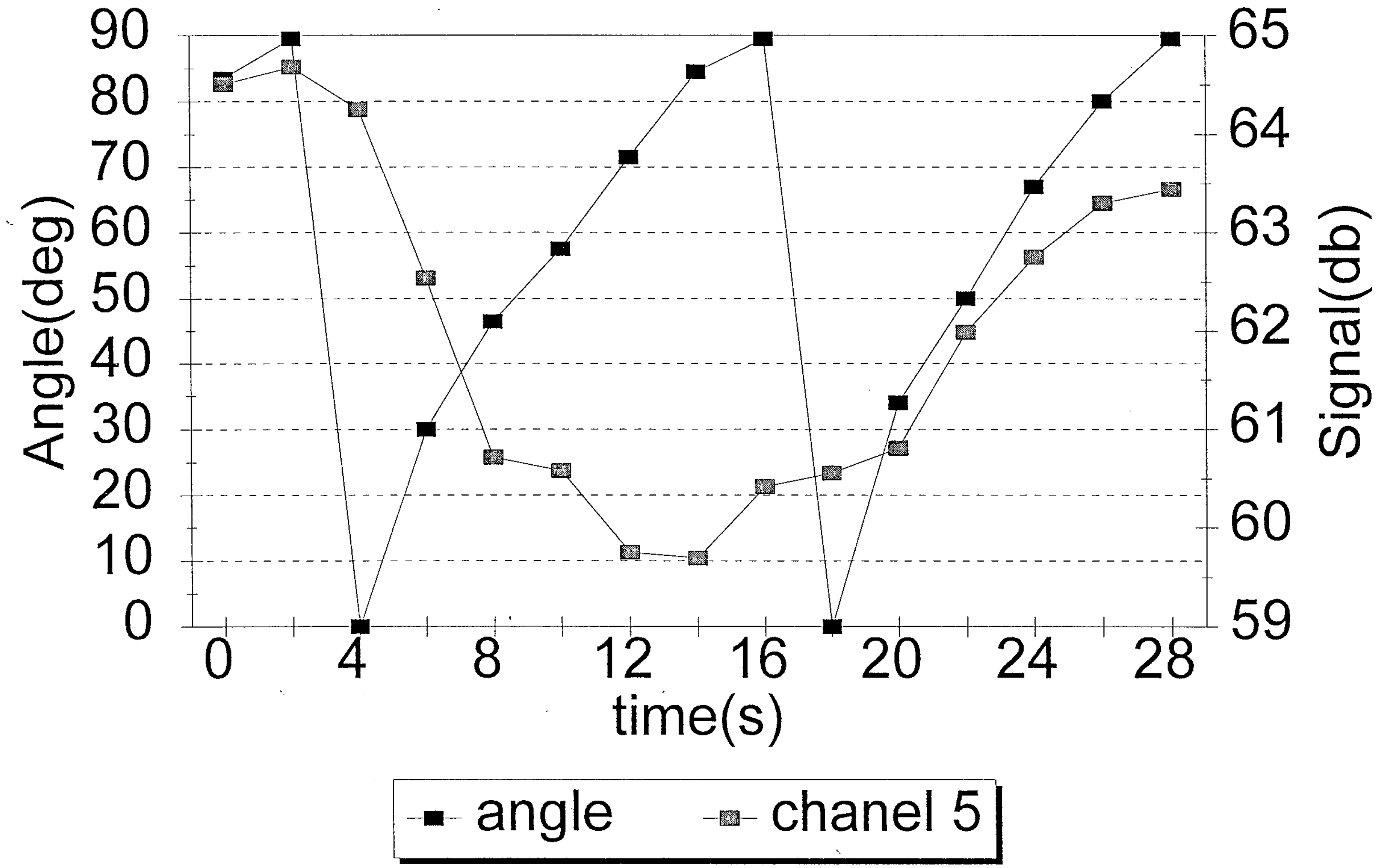
Acoustic path zenith angle vs time

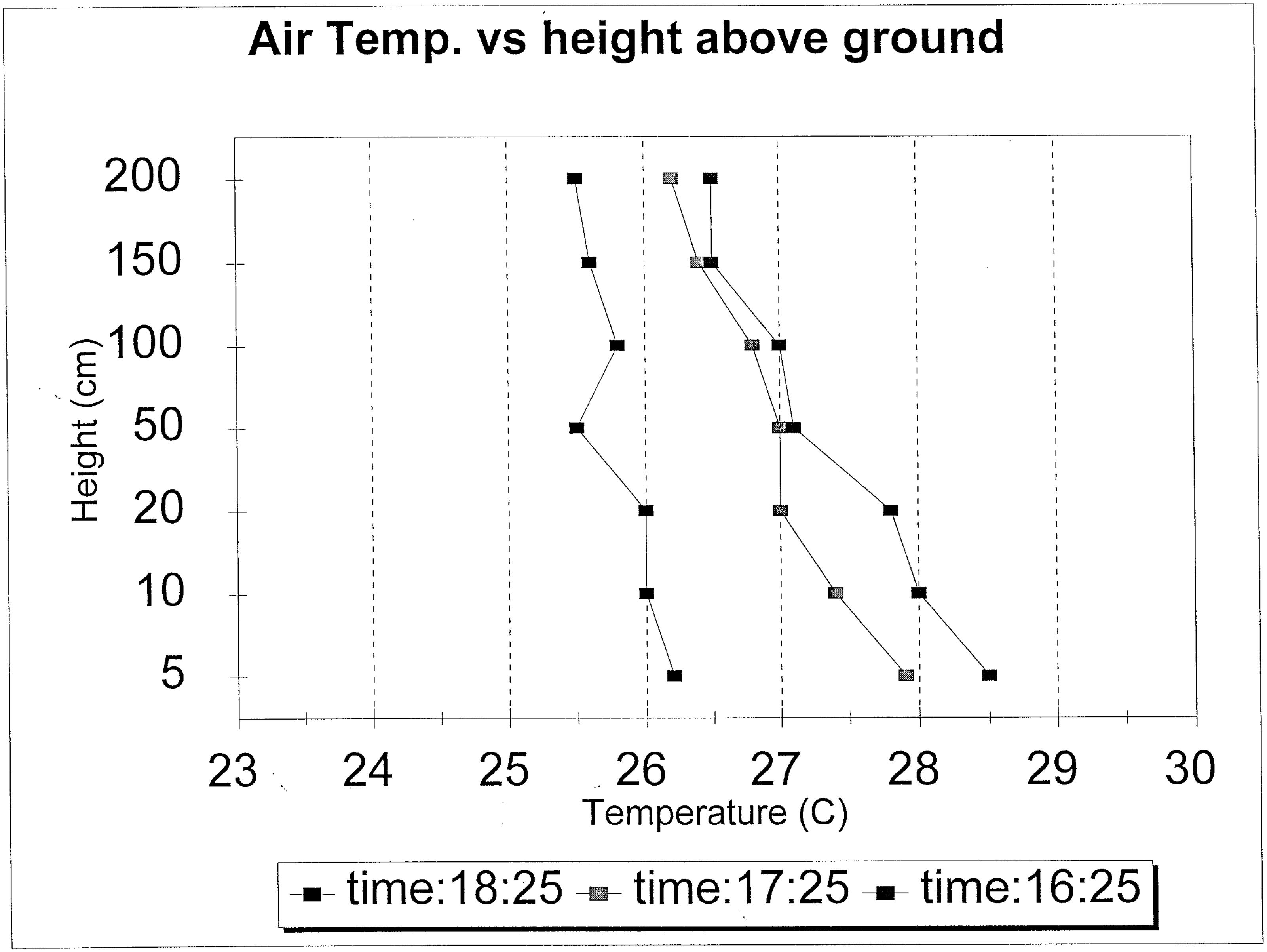
path=800m,s-h/a=1.5/0,r-h=0.95m,300Hz



Acoustic path zenith angle vs time

path=800m,s-h/a=1.5/0,r-h=0.95m,150Hz




Air Temp. vs height above ground
200
150
100
50
20
10
5
Height (cm)
23
24
25
26
27
28
29
30
Temperature (C)
time:18:25
time:17:25
time:16:25

Appendix 2

Best Paper AWARD

THE IMPORTANCE OF DUCTING IN ATMOSPHERIC ACOUSTICS

by

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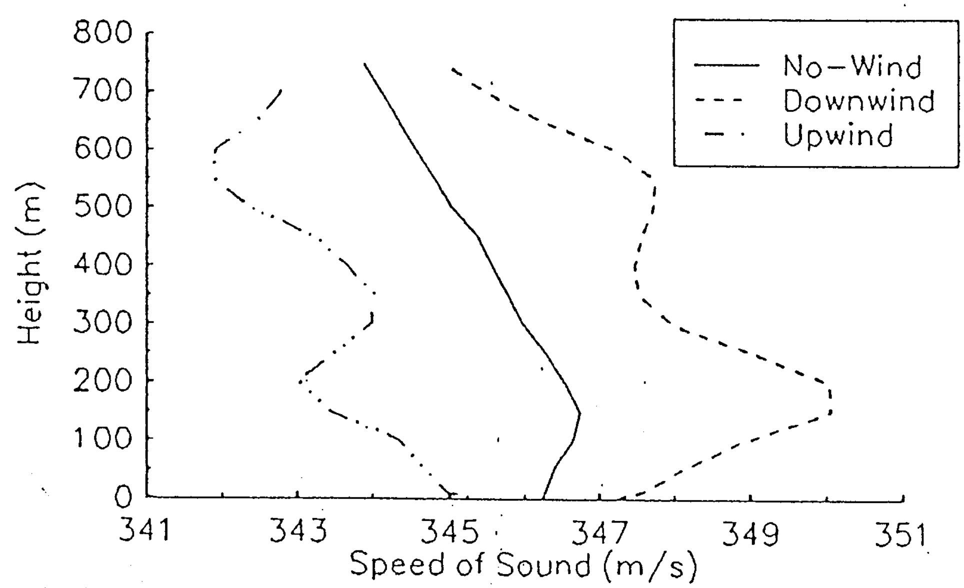
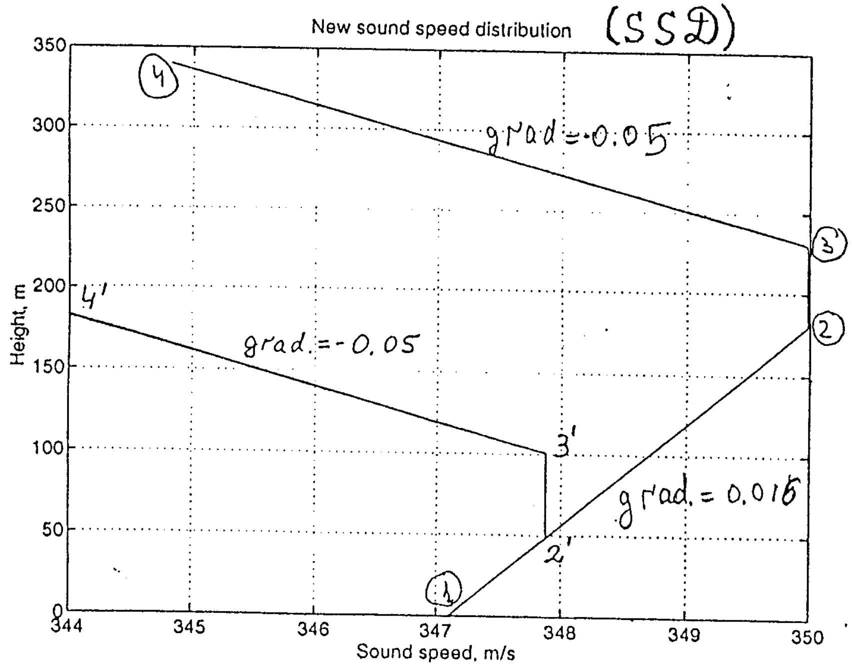
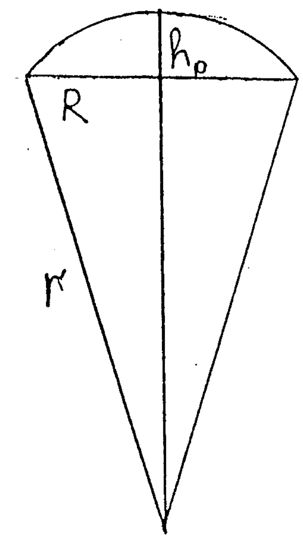


Speed of sound profiles showing the effect of vector wind speed on a nocturnal inversion.





$$r = c \Big/ \frac{dc}{dh}$$

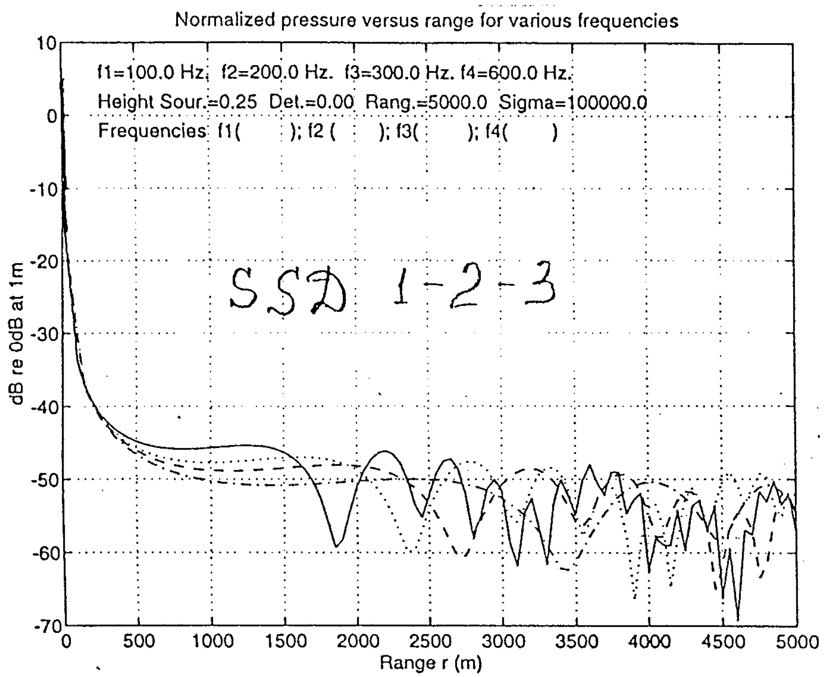
$$h_0 = r - \sqrt{r^2 - (R^2/4)}$$

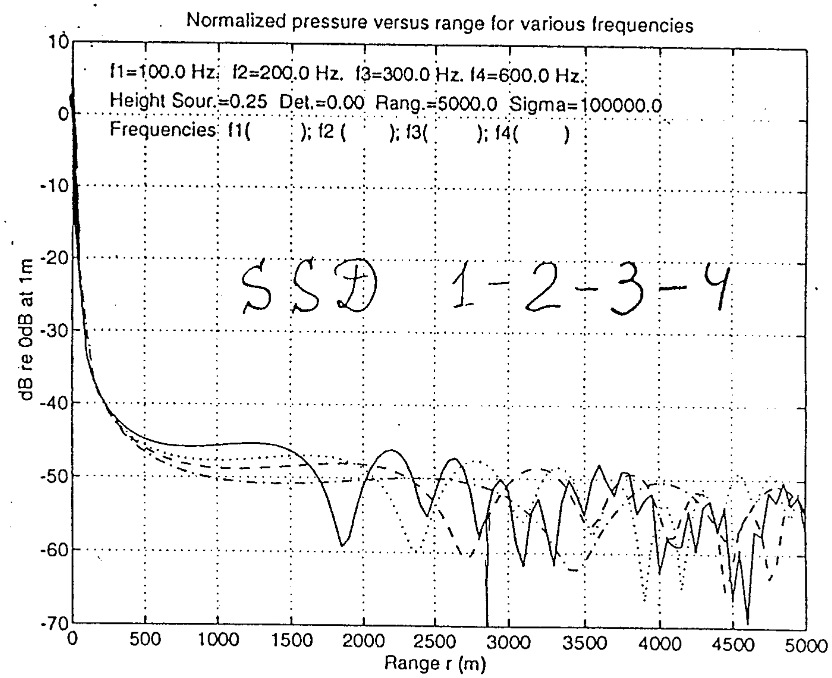
$c = 347.1$ m/sec.

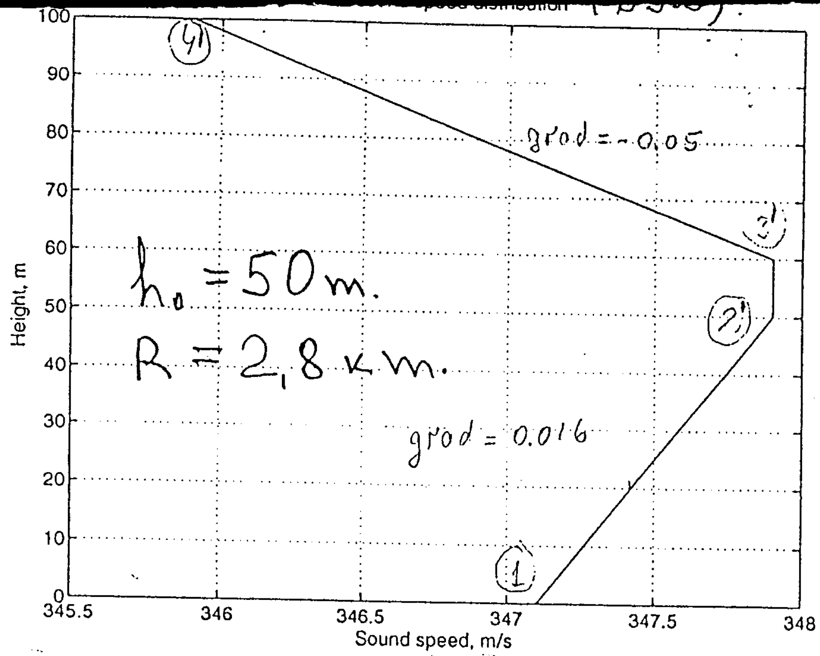
$R = 5$ km, $r = 21$ km

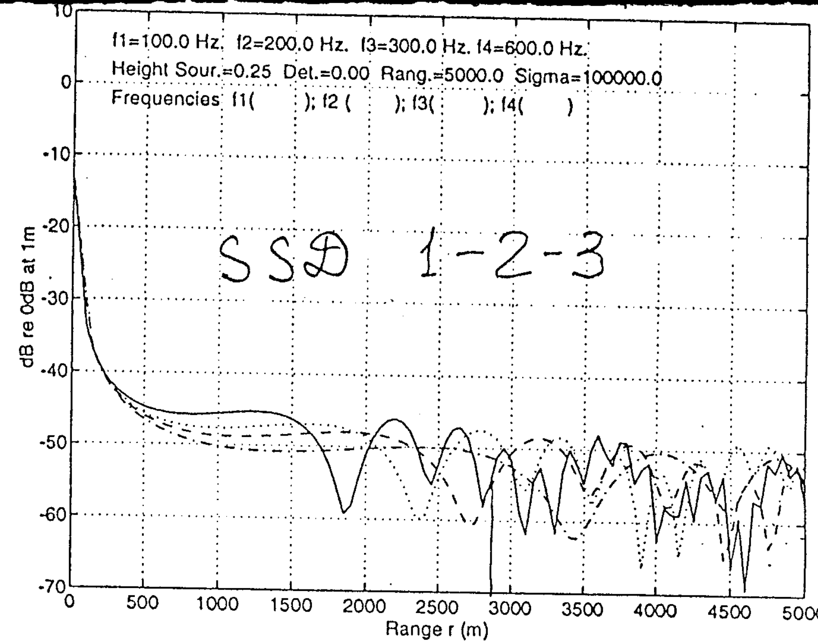
$h_0 = 149$ m

$dc/dh = 0.016$ (1-2)

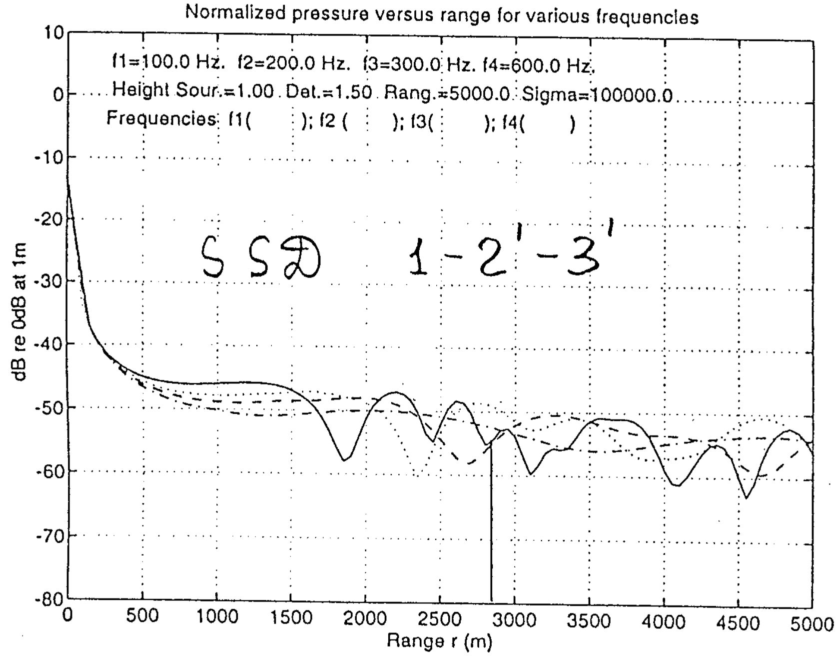




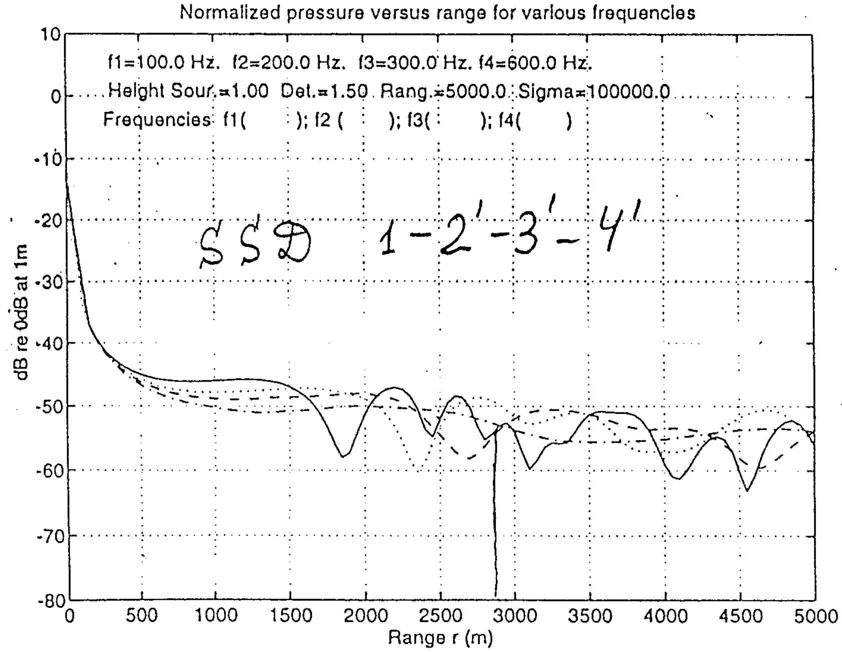


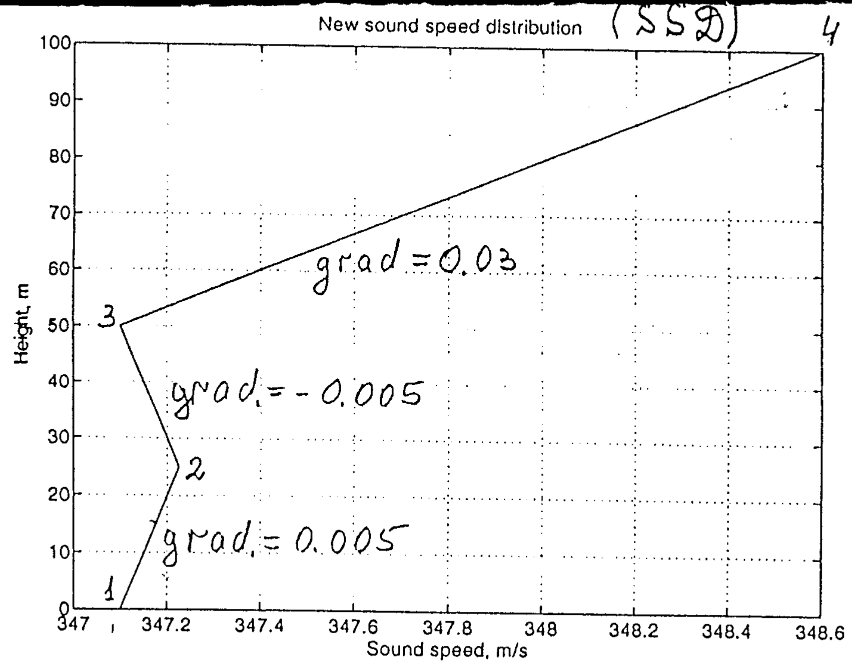


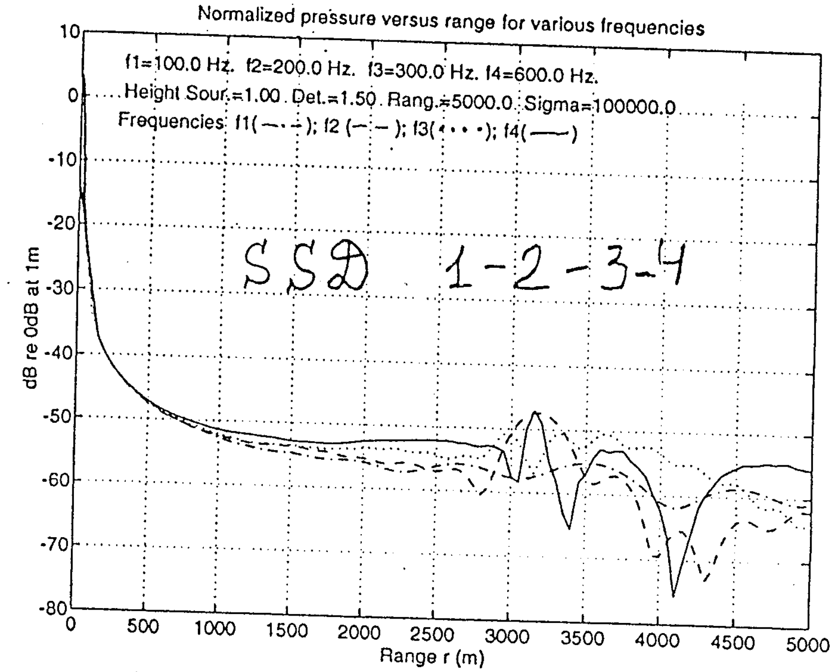
Normalized pressure versus range for various frequencies

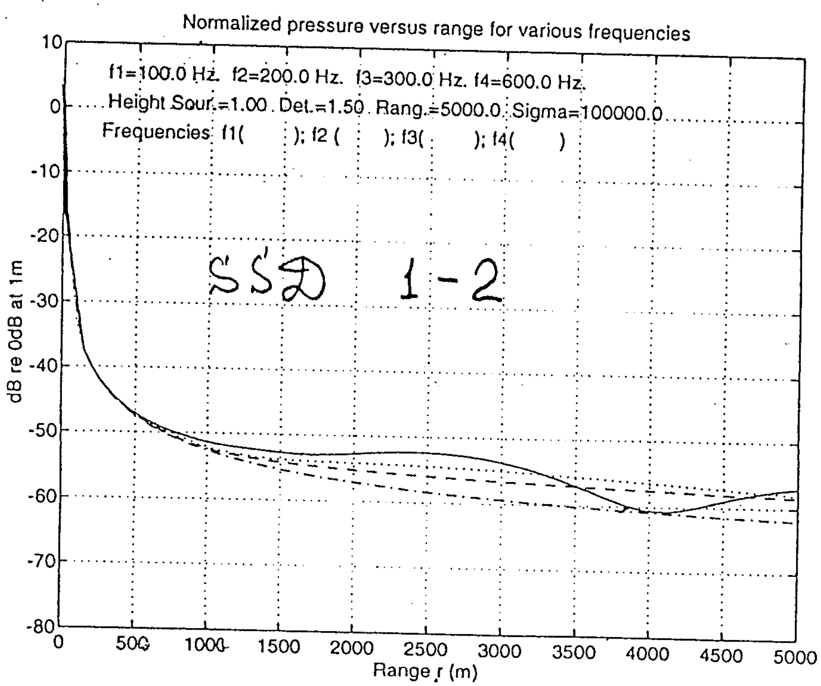


Normalized pressure versus range for various frequencies




New sound speed distribution (SSD)
Height, m
Sound speed, m/s
grad=0.03
grad.=-0.005
grad.=0.005
1
2
3
4


Normalized pressure versus range for various frequencies
f1=100.0 Hz. f2=200.0 Hz. f3=300.0 Hz. f4=600.0 Hz.
Height Sour.=1.00 Det.=1.50 Rang.=5000.0 Sigma=100000.0
SSD 1-2-3-4
dB re 0dB at 1m
Range r (m)


Normalized pressure versus range for various frequencies
f1=100.0 Hz. f2=200.0 Hz. f3=300.0 Hz. f4=600.0 Hz.
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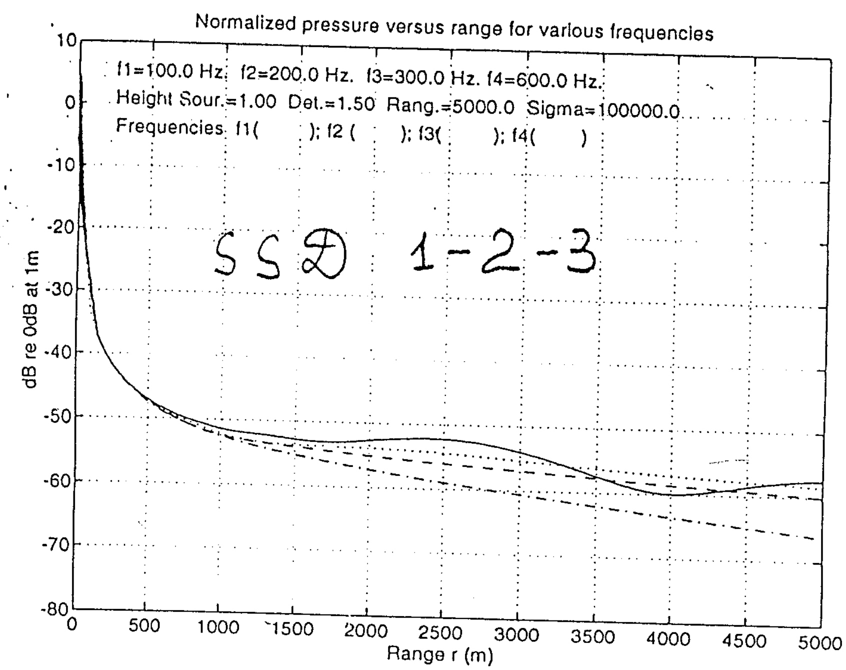
SSD 1-2
dB re 0dB at 1m
Range r (m)


Normalized pressure versus range for various frequencies
f1=100.0 Hz. f2=200.0 Hz. f3=300.0 Hz. f4=600.0 Hz.
Height Sour.=1.00 Det.=1.50 Rang.=5000.0 Sigma=100000.0
SSD 1-2-3
dB re 0dB at 1m
Range r (m)