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GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF RESEARCH ADMINISTRATION

RESEARCH PROJECT INITIATION

Date: August 20, 1975

Project Title: Propagation of Noise from Electric Transformers

Project No: E-25-656

Principal Investigator: Dr. A. D. Pierce

Sponsor: General Electric Company; Rome, Georgia

Agreement Period: From 8/20/75 Until 1/19/76

Type Agreement: Standard Industrial Research Agreement

Amount: $12,300

Reports Required: Monthly Progress

Sponsor Contact Person (s):
Mr. R. A. Nelson, Manager
Advance Development Engineering
Building No. 2, Laboratory
Medium Transformer Department
General Electric Company
Redmond Circle
Rome, Georgia 30161

Assigned to: School of Mechanical Engineering

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Patent Coordinator	Other

RA-3 (6-71)

GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF CONTRACT ADMINISTRATION

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SPONSORED PROJECT TERMINATION

Date: August 3, 1977

Project Title: Propagation of Noise from Electronic Transformers

Project No: E-25-656

Project Director: Dr. A. D. Pierce

Sponsor: General Electric Company; Rome, GA 30161

Effective Termination Date: 12/31/76

Clearance of Accounting Charges: 12/31/76

Grant/Contract Closeout Actions Remaining:

- X Final Invoice ~~and Closing Documents~~
- _ Final Fiscal Report
- _ Final Report of Inventions
- _ Govt. Property Inventory & Related Certificate
- _ Classified Material Certificate
- _ Other ______

NOTE: Continued by E-25-672/Hadden

Assigned to: Mechanical Engineering (School/Laboratory)

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CA-4 (3/76)

Jan 15, 76
Oral Report

TRANSFORMER NOISE PREDICTION PROJECT

General Electric Co.
Medium Transformer Department

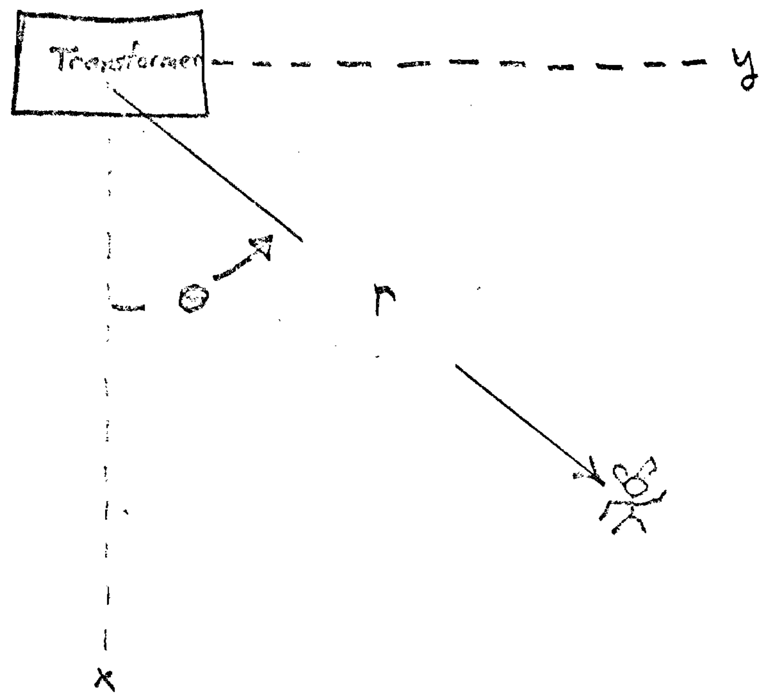
Contractor:

Georgia Institute of Technology
Atlanta, Georgia
Principal Investigator: Dr. Allan D. Pierce
Professor of Mech. Engrg.

OBJECTIVE:

- Given near field acoustic data
- Preferably data from NEMA-type standard test
- Predict far field noise levels
- Capability intended to be offered as standard service to customers
- Information to be used in site selection, orientation of transformers, assessment of possible need for noise control at site

BASIC GEOMETRY OF NOISE DESCRIPTION



In general, Sound pressure level depends on

a) Radial distance r
b) Azimuth angle θ
c) Height z above ground
d) Nature of ground surface
e) Frequency component (120, 240, 360, etc., Hz)

Ideal near field data would be either

a) Knowledge of pressure amplitude and phase at each point on surface enclosing transformer
b) Knowledge of vibrational acceleration amplitude and phase at each point on surface of transformer

Well developed theory, computer programming techniques exist for making far field predictions from complete set of near field measurements. Used extensively in underwater sound experiments.

VALUE OF MODEL FIELD EXPERIMENTS

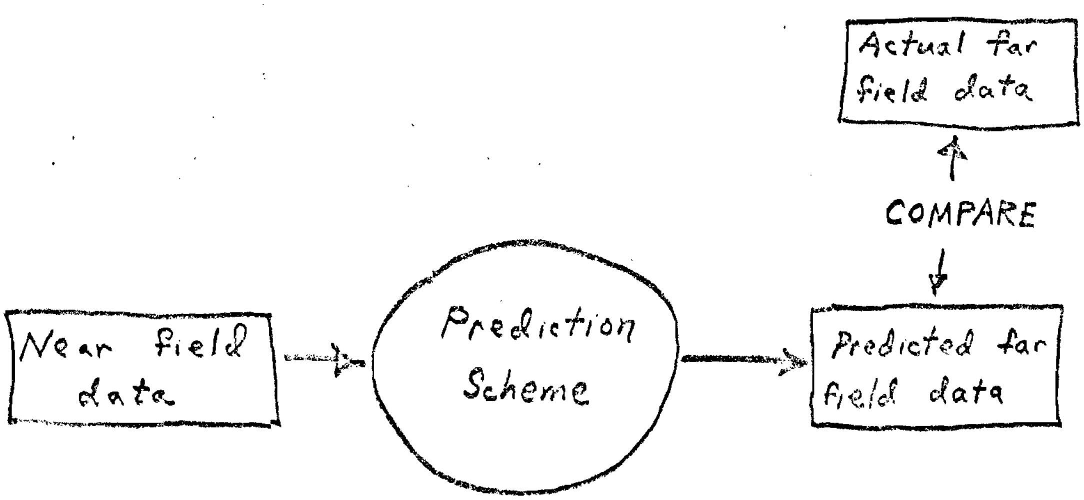
a) Need to know basic acoustic far field of single isolated transformer

b) Once known, techiques exist for predicting environmental noise characteristics of multi-transforme substations, for predicting effects of near-by buildings, barriers, terrain irregularities

c) Isolated single transformer sites in open terrain are difficult to find

d) Given that basic objective is practical and effective near field → far field prediction scheme, model transformer does not have to be completely realistic

e) Data from model field experiments to be used in assessing possible prediction schemes



POSSIBLE PREDICTION SCHEMES:

(A) Crudest conceivable model:

V = volume of transformer

$(SPL)_{NEMA}$ = sound pressure level from NEMA test

$$a = \left(\frac{3V}{2\pi}\right)^{1/3} = \text{radius of "equivalent" hemisphere}$$

$$(SPL)_{\text{Radius } r} = (SPL)_{NEMA} - 10 \log_{10}(r/a)^2$$

No azimuth dependence predicted

Predicts 6 dB drop per doubling of distance

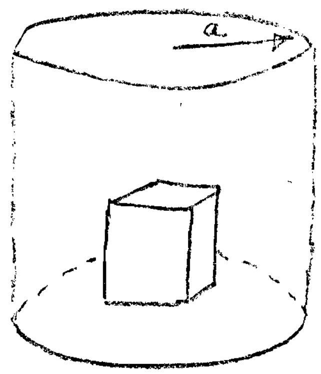
Example: 126 Hz source in model transformer

$a = 3.1$ ft

		$10 \log_{10}(r/a)^2$	Should be $(SPL)_{NEMA}$
$(SPL)_{NEMA}$	= 90 dB		
$(SPL)^{AVE}_{10\,ft}$	= 73 dB	10 dB	73+10 = 83 dB
$(SPL)^{AVE}_{20\,ft}$	= 71 dB	16 dB	71+16 = 87 dB
$(SPL)^{AVE}_{40\,ft}$	= 68 dB	22 dB	68+22 = 90 dB

Agreement not too bad on average at larger distances

(B) Refined model



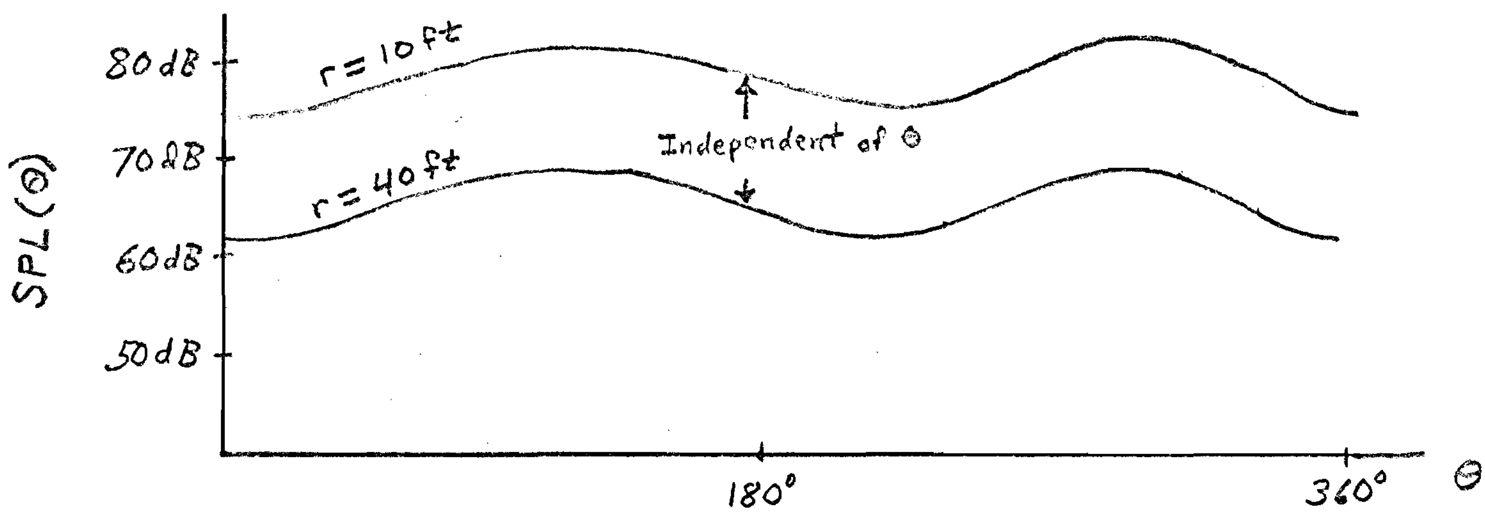
Hypothetical cylinder enclosing transformer

Near field sound pressure level known on cylinder as function of azimuth angle θ

$$SPL(\theta) \text{ at radius } r = SPL(\theta) \text{ at radius } a - (\text{Function of } r, a, \lambda)$$

λ = (sound speed)/(frequency) = wavelength

Model predicts that plots of $SPL(\theta)$ vs. θ for fixed r are similar for different r.



(B) Refined model - continued

Theory with many simplifying assumptions suggests:

SPL decreases as 3dB per doubling of distance at smaller r

SPL decreases as 6dB per doubling of distance at larger r

$$\left[\text{Function of } r, a, \lambda\right] \cong 10 \log_{10}(r/a) + \left\{\text{Depends on } \lambda r/h^2\right\}$$

h = height of transformer

$$\left\{\text{Depends on } \lambda r/h^2\right\} \approx 0 \quad \text{at small } r$$

$$\approx 10 \log_{10}\left(\lambda r/2h^2\right) \quad \text{at large } r$$

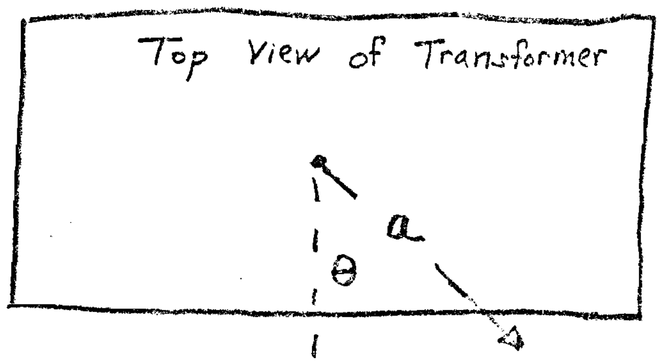
$\frac{2h^2}{\lambda} \approx 5$ ft for our model experiments

Transition occurs near

$\frac{\lambda r}{2h^2} \approx 3$ to 6 [r ≈ 15 ft to 30 ft in our model experiments]

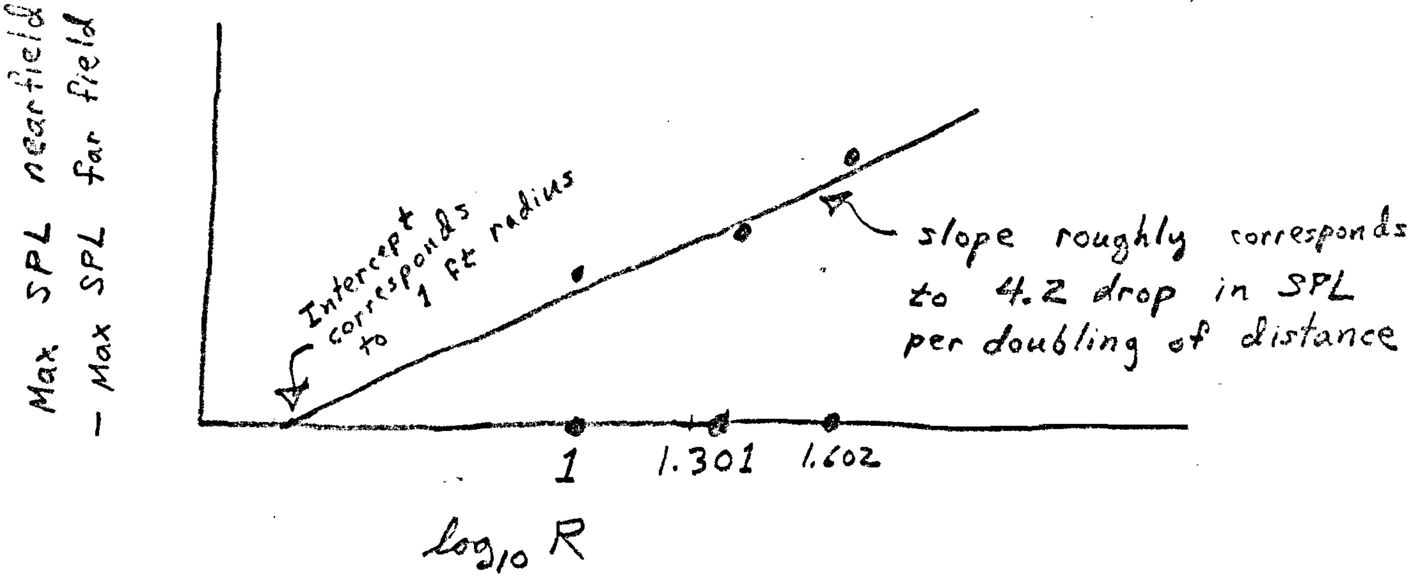
(B) Refined model - <u>implementation</u>

For predictions based on NEMA type data



For model transformer, a varies from 1 ft to 5 ft.

Appropriate choice of a appears to be closer to 1 ft



(B) Refined model – implementation

Since SPL data on surface of transformer is erratic with Θ, we examined possibility of predicting $SPL(\Theta)$ vs. Θ at 20 ft and 40 ft radii from data taken at 10 ft radii.

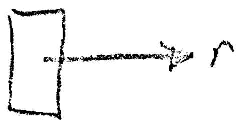
Data is consistent with formula

$$(SPL(\Theta))_{radius\ r} \approx (SPL(\Theta))_{radius\ a} - 10 \log_{10}(r/a)^{1.33}$$

$a \approx 10$ ft.

Curves of prediction based on above formula are compared with curves of $SPL(\Theta)_{radius\ r}$ vs. Θ.

Comments on ground effects



Sample data from model experiments

r	SPL(r)	ΔSPL	
10 ft	95.5 dB		
		3.5 dB	cylindrical spreading
20 ft	92.0		
		4.5	
40 ft	87.5		
		5.0	spherical spreading
80 ft	82.5		
		11.0	anomalous ground absorption
160 ft	71.5		

Data indicates that drop-off greater than 6 dB per doubling of distance occurs between 80 ft and 160 ft. This is attributed to fact that ground is not perfectly rigid and is consistent with established theory.

Effect can be taken into account in prediction model but it seems important at the present to concentrate on predictions up to 80 ft distance where ground effects are not substantial.

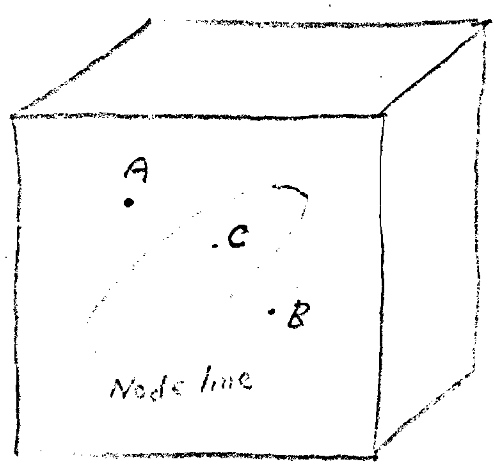
Proposed Next Phase of Program

1. It appears NEMA type data without some additional knowledge of near field is insufficient for accurate far field predictions.

2. It is envisioned that one can develope a general prototype model of transformer surface vibrations with parameters that can be determined from NEMA type data

3. Given prototype model and parameters one can make accurate far field predictions

4. Prototype model

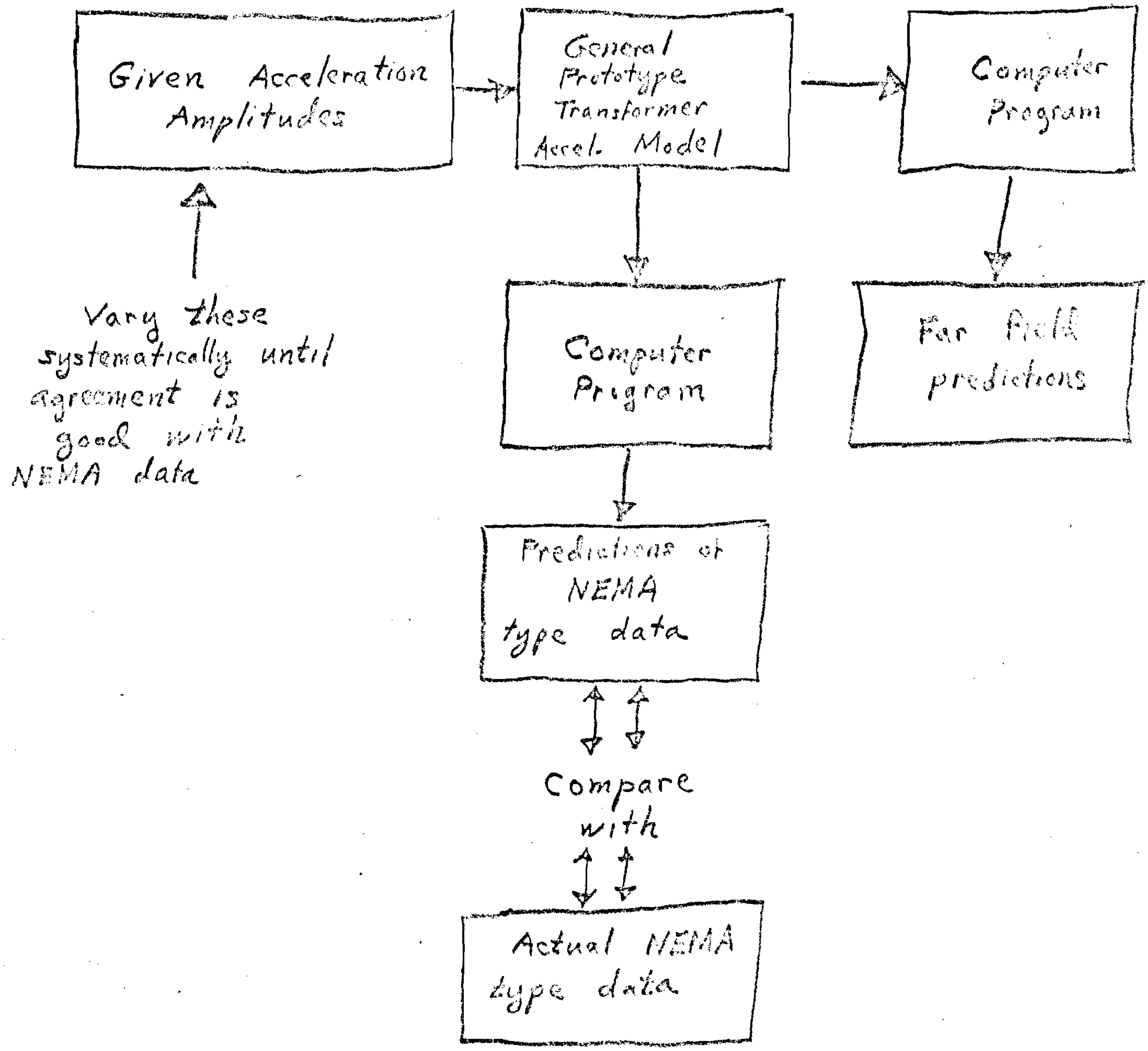


Assumed that on surface, accelerations at any two points (at given discrete frequen component) are either in phase or out of phase by 180°.

Node lines where acceleration is zero are in nearly the same place for given frequency for all transformers of similar dimensions.

Given node lines or approximate node lines, one devises an acceleration amplitude function which vanishes on node line and has undetermined amplitudes in centers of node cells.

An approximate model (represented by computer program) of whatever sophistication needed is developed for predicting near field pressures from acceleration model.



Given Acceleration Amplitudes
General Prototype Transformer Accel. Model
Computer Program
Vary these systematically until agreement is good with NEMA data
Computer Program
Far field predictions
Predictions of NEMA type data
Compare with
Actual NEMA type data

Experiments to be performed:

1) In semi-anechoic chamber at GE

2) Need consistent sets (taken under similar conditions for same transformer) of near field accelerometer data and near field pressure data.

3) Determine vibrational amplitudes and node lines from data.

4) Develop (based on existing successful techniques) computer program for predicting near field pressure data from acceleration data.

5) Check for consistency of vibration patterns on similar transformers.

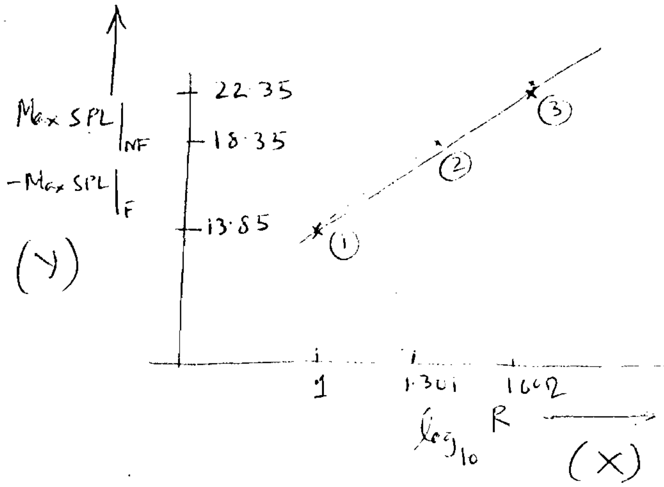
6) Develop system of working backwards from NEMA data to obtain vibration patterns

7) Develop system for intermediate and far field predictions from vibration model.

8) Check out system as much as possible in semi-anechoic chamber.

9) Check out further with field experiments

10) Refine model to include ground effects and terrain effects, barriers, etc.



We want to fit a st. line through these 3 data points by the method of least squares.

If the ~~given~~ eqn of the st. line is given by

$y = A + Bx$, where $y = SPL_{NF} - SPL_F$

Method of least squares says,

$x = \log_{10} R$

$A \equiv$ y-intercept

$B \equiv$ slope

$n \equiv$ no of points.

$$\text{Slope } B = \frac{n\sum xy - \sum x \sum y}{n\sum x^2 - (\sum x)^2}$$

$$\text{y-intercept } A = \frac{\sum x^2 \sum y - \sum x \sum xy}{n\sum x^2 - (\sum x)^2}$$

$\log_{10} R$ (x)	$SPL_N - SPL_F$ (y)	x^2	xy
1	13.85	1	13.85
1.301	18.35	1.69	23.87
1.602	22.35	2.57	35.80
$\sum x = 3.903$	$\sum y = 54.55$	$\sum x^2 = 5.26$	$\sum xy = 73.52$

$$\therefore \text{Slope } B = \frac{3(73.52) - (3.903)(54.55)}{3(5.26) - (3.903)^2} = \frac{7.65135}{0.546591}$$

$$= 13.998 \simeq 14.0$$

$$\text{y intercept } A = \frac{(5.26)(54.55) - (3.903)(73.52)}{3(5.26) - (3.903)^2}$$

$$= \frac{-0.01556}{0.546591} = -0.028.$$

Now, $y = A + Bx$

$$\Rightarrow \quad SPL_{NF} - SPL_F = A + B \log_{10} R$$

$$= 10 \log_{10} \left(R/R_0 \right)^N$$

where $A = -10N \log_{10} R_0$

and $B = 10N$

$10N = B = 14.0$

$\therefore \boxed{N = 1.4}$

$-10N \log_{10} R_0 = A = -0.028$

$$\Rightarrow \quad R_0 = 10^{\frac{.028}{10N}} = 10^{\frac{.028}{14}} = 1.0046$$

$$\boxed{R_0 = 1.005}$$

$$SPL_F = SPL_{NF} - 10 \log_{10} \left(\frac{R}{1.005} \right)^{1.4}.$$

For $R = 10\,ft$, $\quad 10\log_{10}\left(\frac{R}{R_0}\right)^N = 10N\log\left(\frac{10}{1.005}\right) = 14.0$

$$\therefore \boxed{SPL_{Far} = SPL_{Near} - 14.0}$$

For $20\,ft$, $\quad 10\log_{10}\left(R/R_0\right)^N = 10N\log_{10}\left(\frac{20}{1.005}\right) = 18.2$

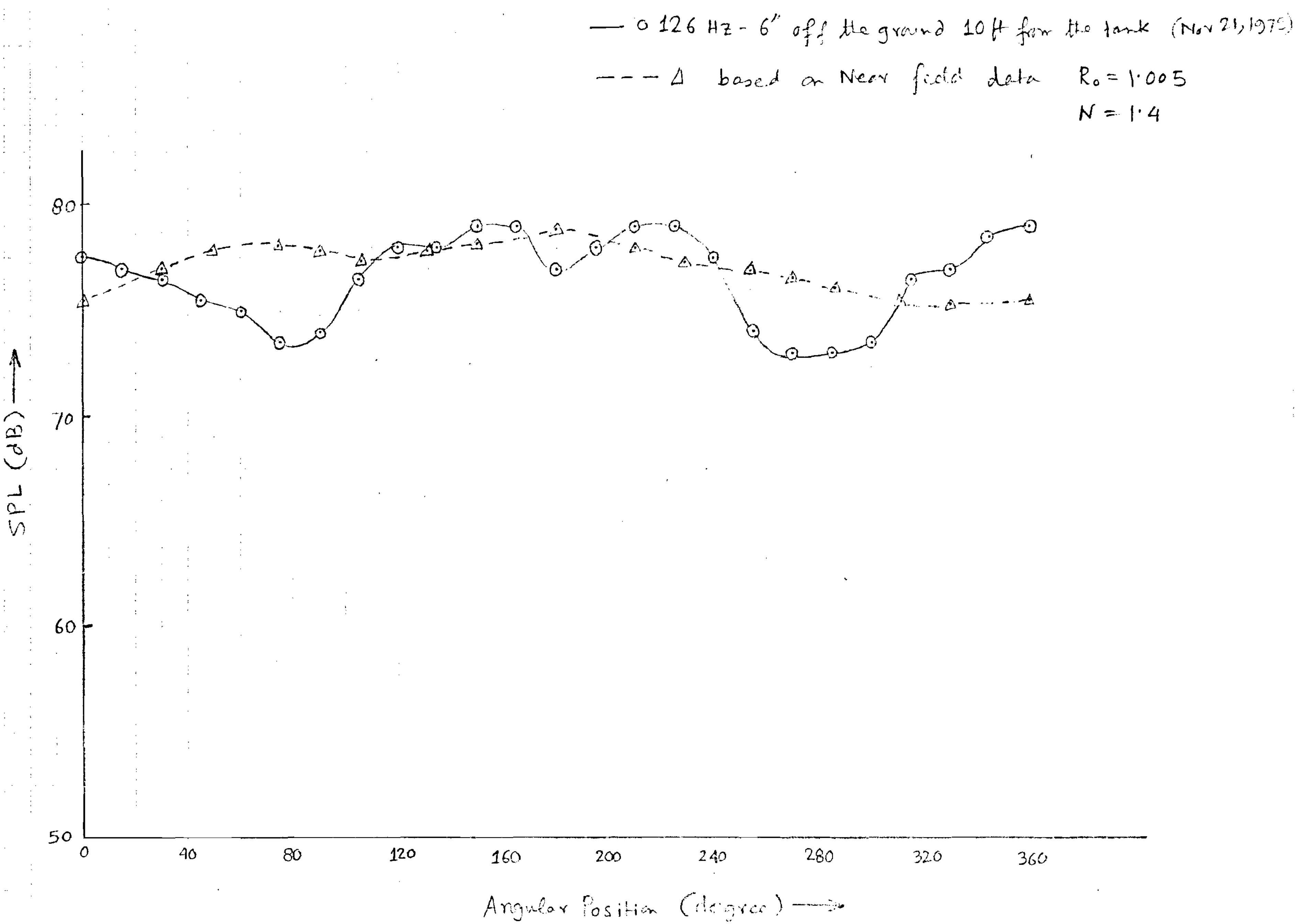
$$\therefore \boxed{SPL_{Far} = SPL_{Near} - 18.2}$$

For $40\,ft$ $\quad 10\log_{10}\left(R/R_0\right)^N = 10N\log_{10}\left(\frac{40}{1.005}\right) = 22.40$

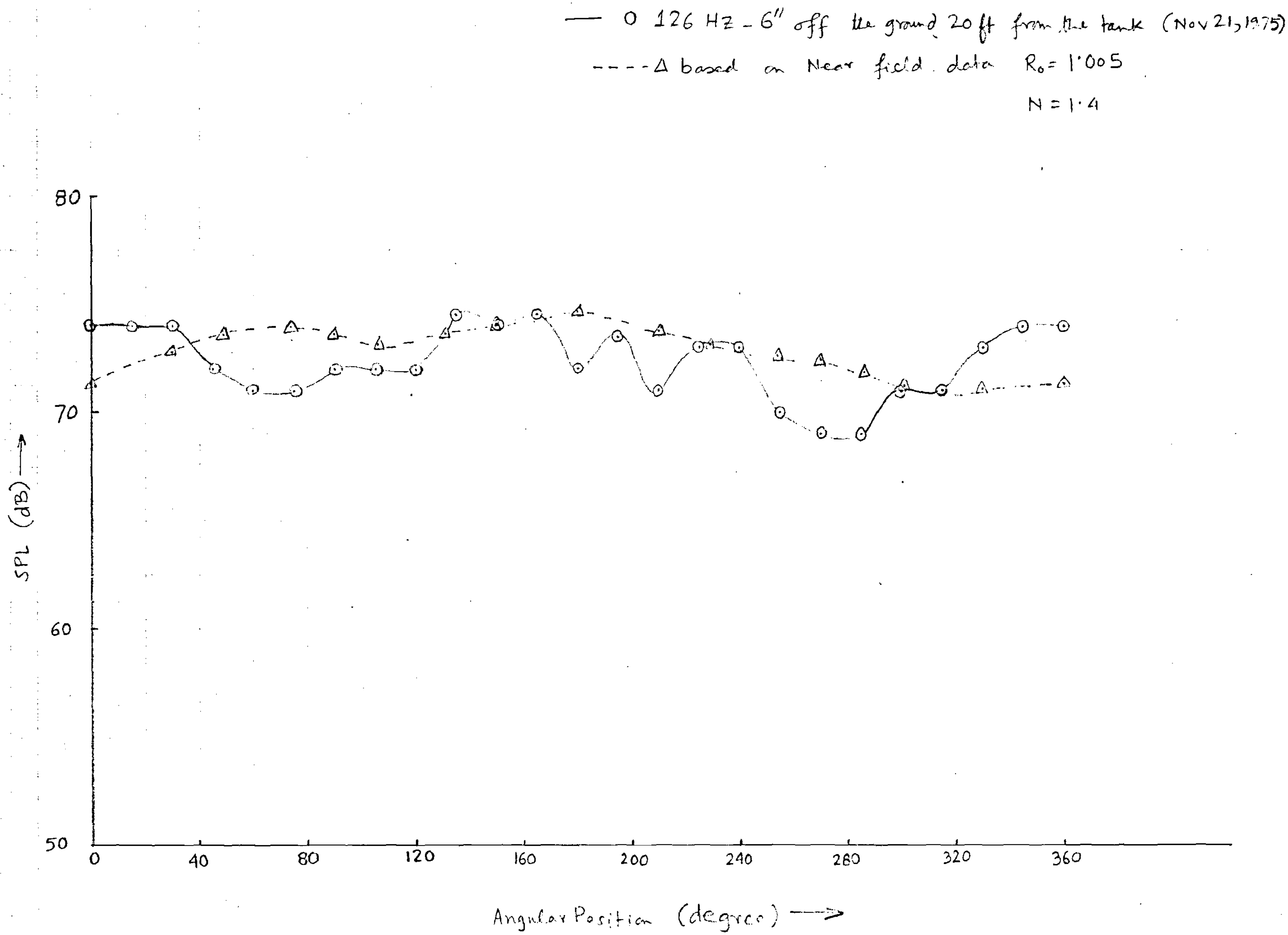
$$\therefore \boxed{SPL_{Far} = SPL_{Near} - 22.4}$$

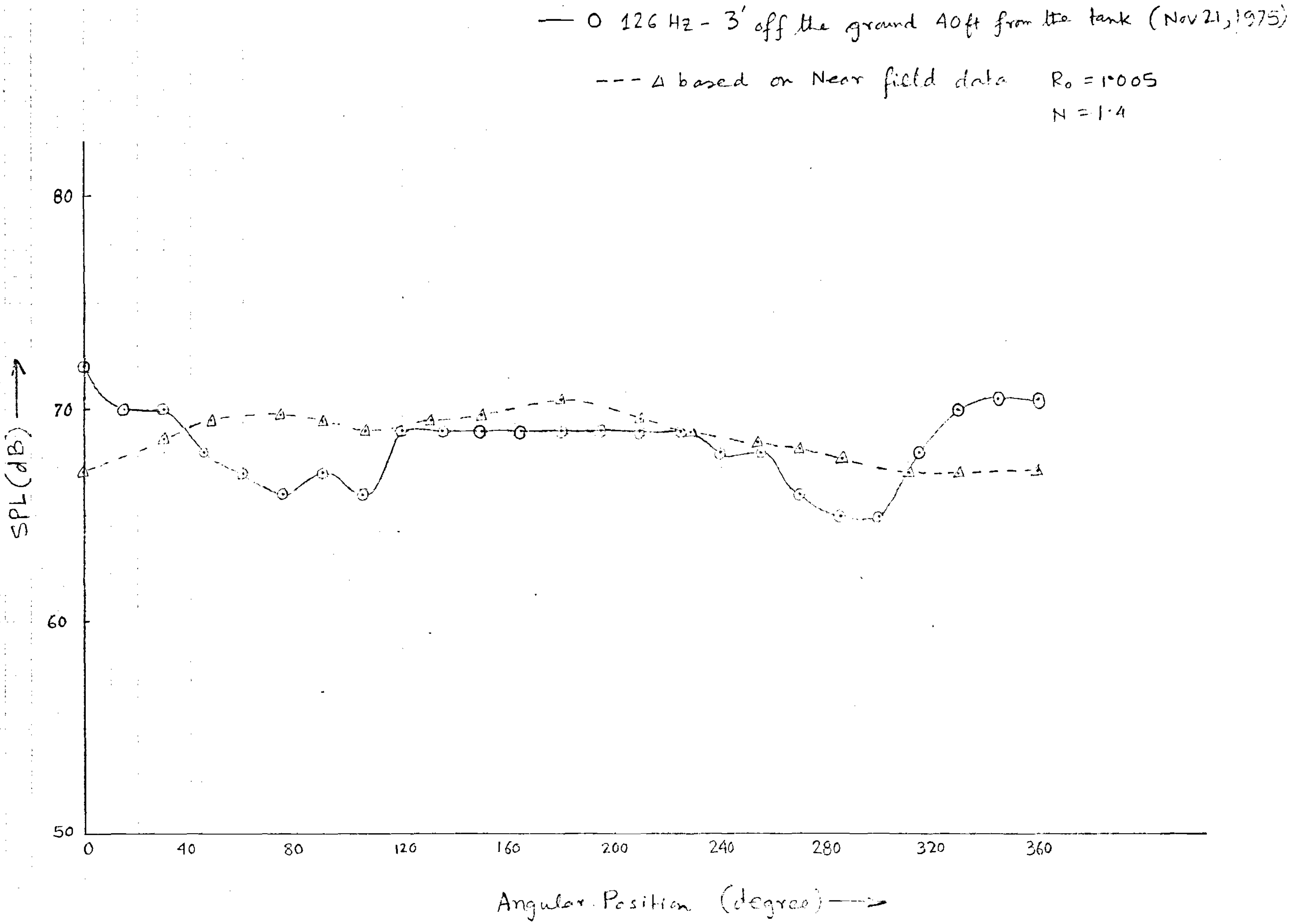
The Smoothed Near Field Data are:

Angle (degree)	S.P.L (dB)
0	89.5
30	91.0
49	91.85
74	92.1
90	91.85
106	91.35
131	91.85
150	92.15
180	92.85
210	92.0
229	91.35
254	90.55
270	90.6
286	90.1
311	89.45
330	89.35
360	89.5

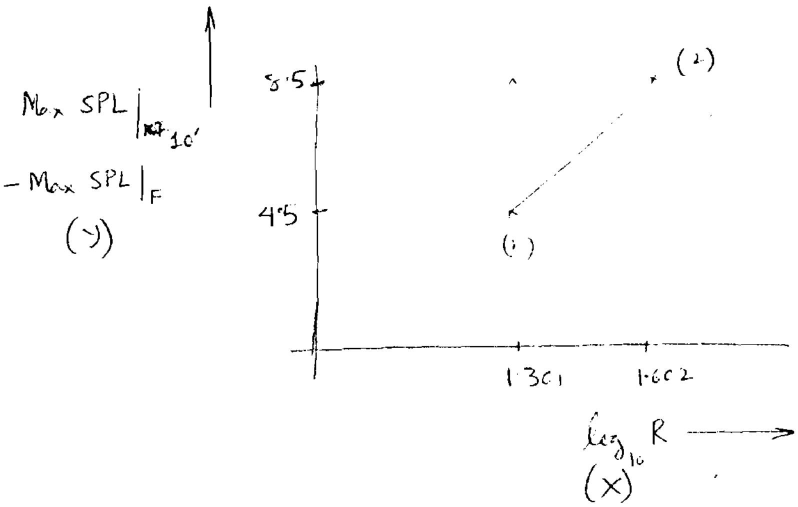


— o 126 Hz - 6" off the ground 10 ft from the tank (Nov 21, 1975)
- - - Δ based on Near field data
R₀ = 1·005
N = 1·4
SPL (dB) ⟶
80
70
60
50
0
40
80
120
160
200
240
280
320
360
Angular Position (degree) ⟶


— O 126 HZ - 6" off the ground 20 ft from the tank (Nov 21, 1975)
- - - - Δ based on Near field data R_0 = 1·005
N = 1·4
80
70
60
50
SPL (dB) ⟶
0
40
80
120
160
200
240
280
320
360
Angular Position (degree) ⟶



— O 126 Hz - 3' off the ground 40 ft from the tank (Nov 21, 1975)
--- Δ based on Near field data R₀ = 1·005
N = 1·4
SPL (dB) →
80
70
60
50
0
40
80
120
160
200
240
280
320
360
Angular Position (degree) →



Eqn of the st. line passing through the two pts (1) & (2)
is $y = A + Bx$ where A = y-intercept
B = slope

The eqn of a st. line passing through the points
$(1.301, 4.5)$ and $(1.602, 5.5)$ is

$$\boxed{y = 13.29x - 12.79}$$

Comparing with $y = A + Bx$

y-intercept $A = -12.79$

Slope $B = 13.29$.

$$SPL_{10} - SPL_F = A + B \log_{10} R$$
$$= 10 \log_{10} (R/R_0)^N.$$

where, $B = 10N = 13.29 \Rightarrow \boxed{N = 1.33}$

and $-10N \log_{10} R_0 = A = -12.79$

$$\therefore R_0 = 10^{\frac{12.79}{13.3}} = 9.15$$

or $\boxed{R_0 = 9.15}$

For $R = 20 ft$

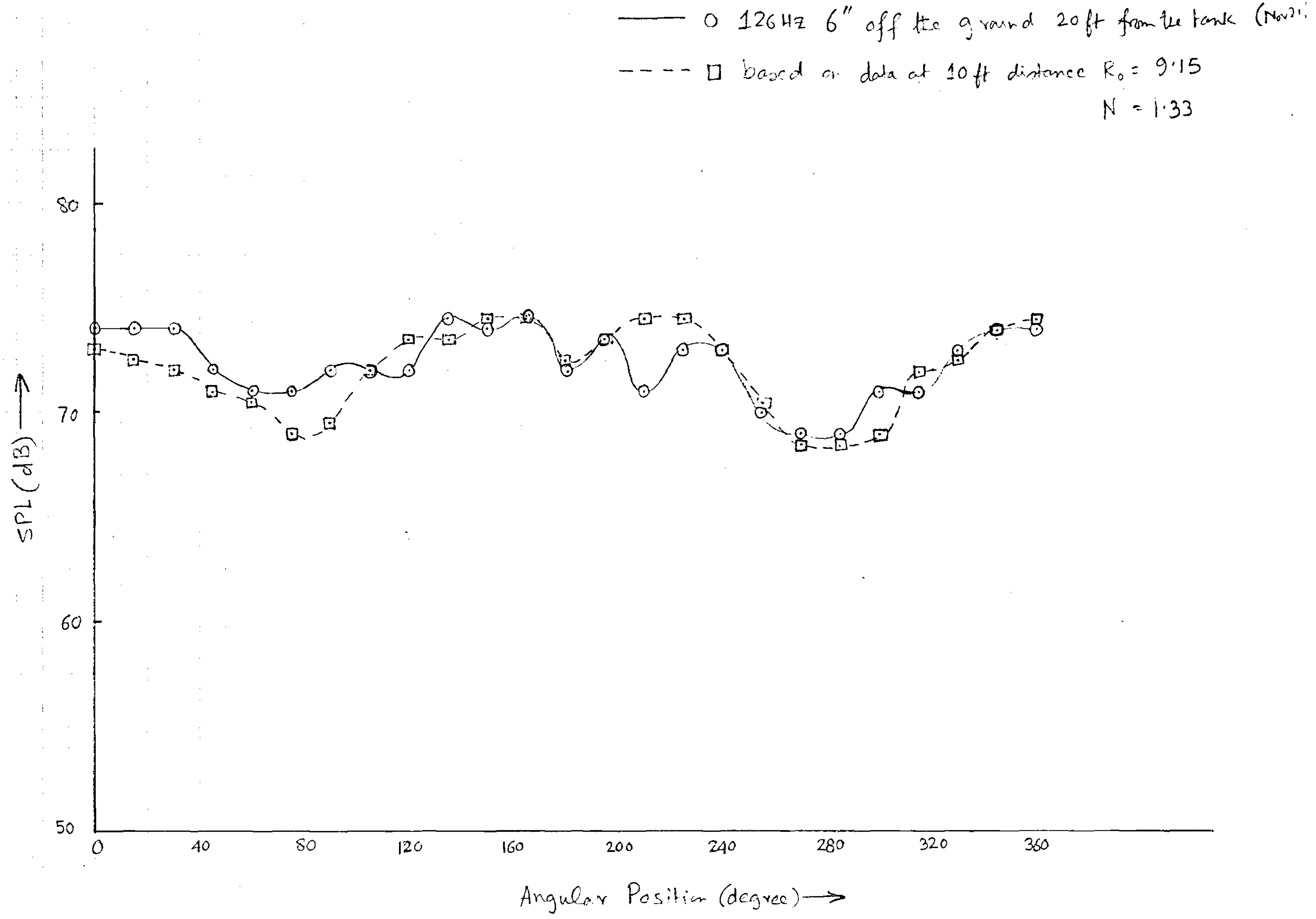
$$SPL_{10} - SPL_{Far} = 10 \log_{10}(R/R_0)^N = 10 N \log\left(\frac{20}{9.15}\right) = 4.52$$

a) $\boxed{SPL_{Far} = SPL_{10} - 4.52}$

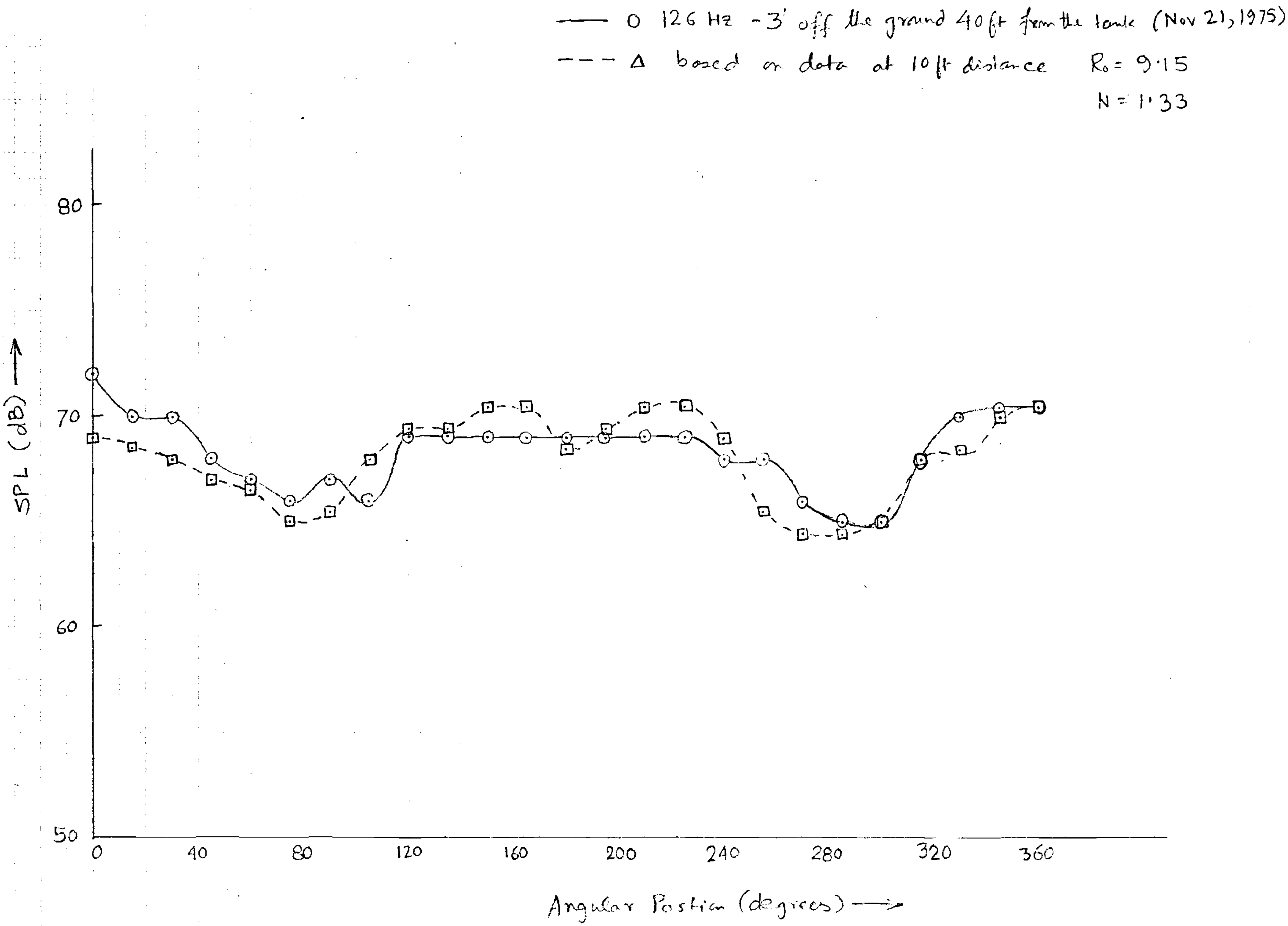
Similarly,

For $R = 40 ft$,

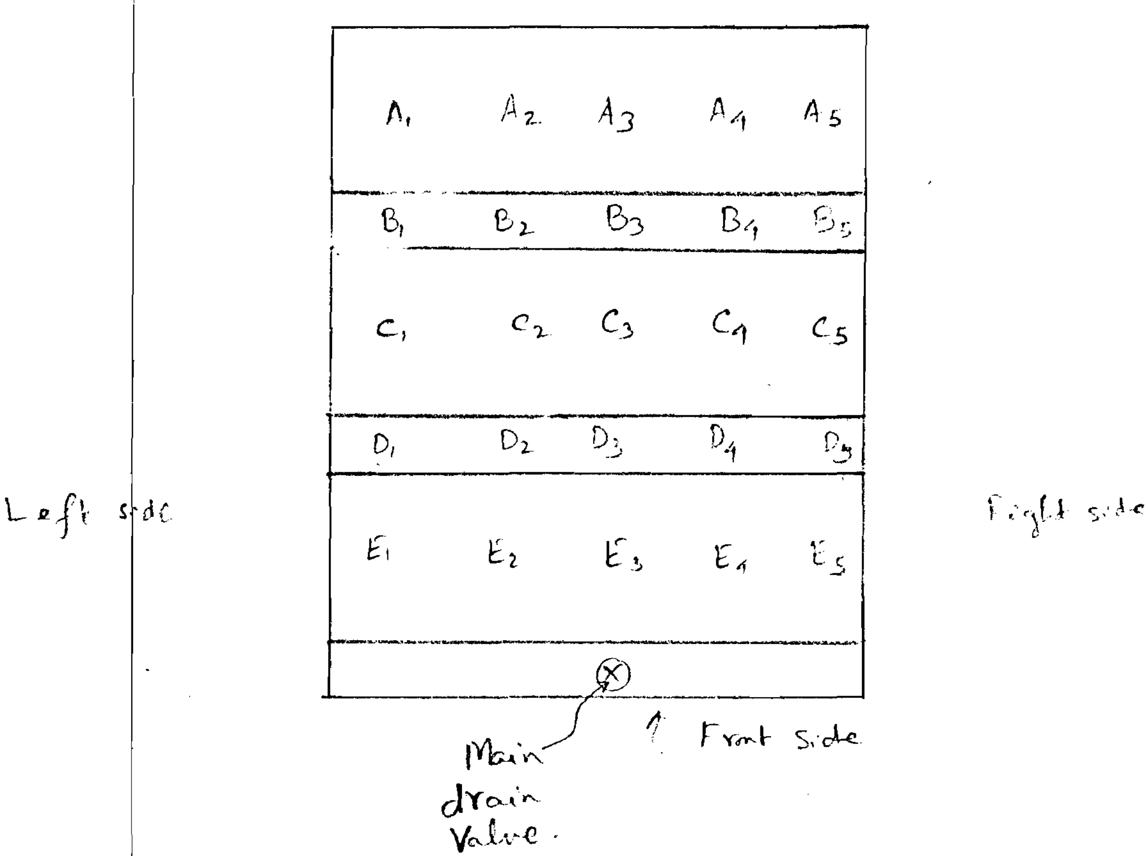
$$\boxed{SPL_{Far} = SPL_{10} - 8.52}$$



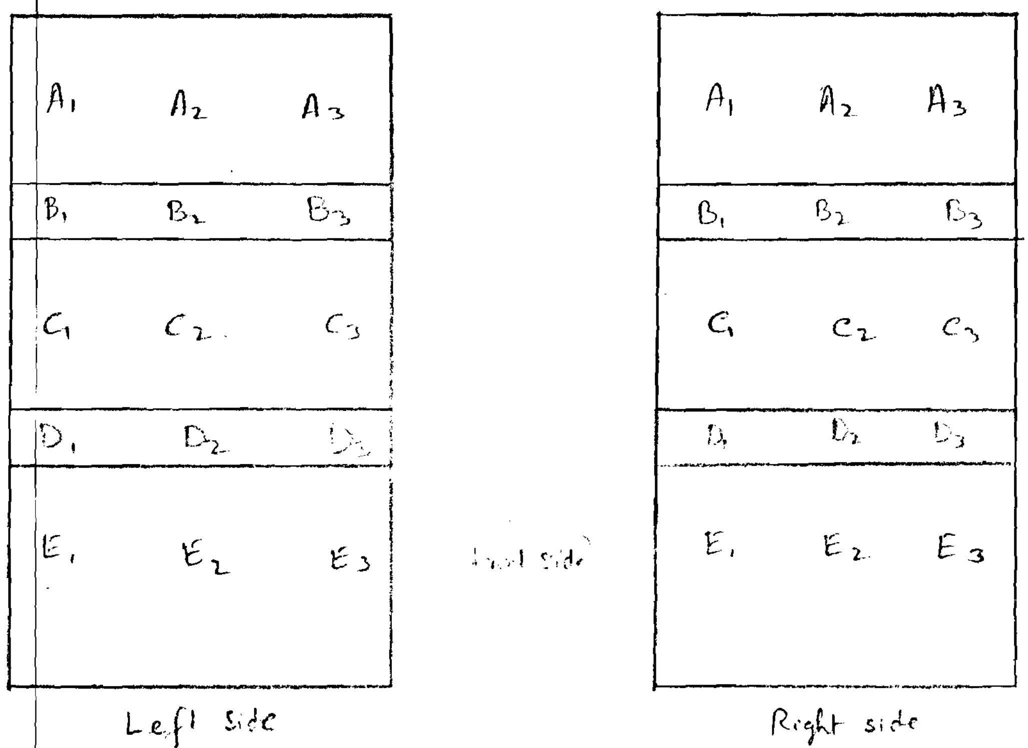
O 126 Hz 6" off the ground 20 ft from the tank (Nov 21
□ based on data at 10 ft distance R0 = 9.15
N = 1.33
SPL (dB)
80
70
60
50
0
40
80
120
160
200
240
280
320
360
Angular Position (degree)

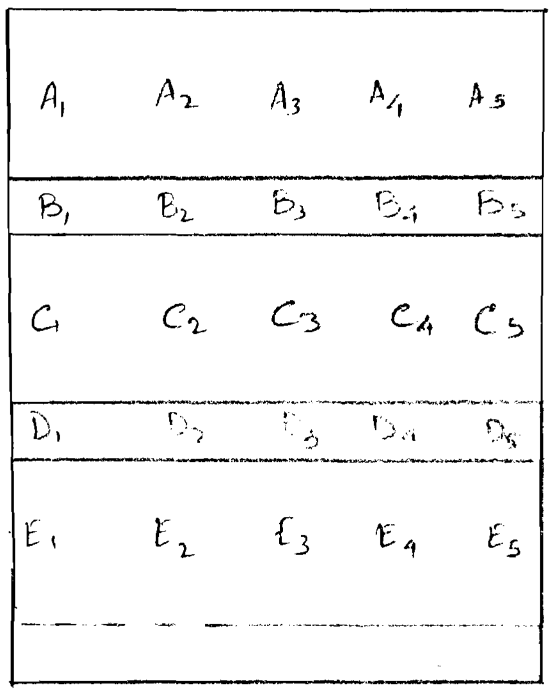


— O 126 Hz - 3' off the ground 40 ft from the tank (Nov 21, 1975)
- - - Δ based on data at 10 ft distance R₀ = 9.15
N = 1.33
SPL (dB)
80
70
60
50
0
40
80
120
160
200
240
280
320
360
Angular Position (degrees)



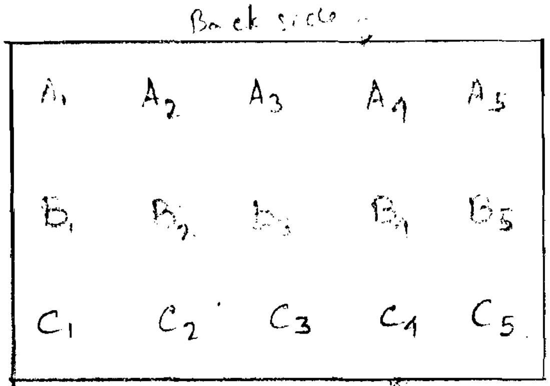
A1 A2 A3 A4 A5
B1 B2 B3 B4 B5
C1 C2 C3 C4 C5
D1 D2 D3 D4 D5
E1 E2 E3 E4 E5
Left side
Right side
Front side
Main drain Valve.


A1 A2 A3
B1 B2 B3
C1 C2 C3
D1 D2 D3
E1 E2 E3
Left side
A1 A2 A3
B1 B2 B3
C1 C2 C3
D1 D2 D3
E1 E2 E3
Right side



Rear Side

Back side



Top. front side.

Nov 21, 1975

Near Field Sound Pressure Levels of the transformer

SLM set at slow - ext filter
125 Hz octave band.

Front Side		Right Side.		Back Side		
Position	Sound Pressure Level (dB)	Postion	Sound Pressure Level (dB)	Position	S.P.L. (dB)	
A_1	93	A_1	76	A_1	89	
A_2	99	A_2	85	A_2	96	
A_3	101	A_3	87	A_3	99	
A_4	98			A_4	97	
A_5	93			A_5	90.5	
B_1	91	B_1	82	B_1	87.5	
B_2	96.5	B_2	88.5	B_2	94	
B_3	97	B_3	88.5	B_3	98	
B_4	96			B_4	95.5	
B_5	91			B_5	89.5	
C_1	91.5	C_1	87	C_1	88	
C_2	92	C_2	94	C_2	89.5	
C_3	82	C_3	91	C_3	97.5	
C_4	94			C_4	92	
C_5	91			C_5	80.5 ×	[illegible]
D_1	86	D_1	85	D_1	87	
D_2	91.5	D_2	88	D_2	88	
D_3	95	D_3	86.5	D_3	84.5	
D_4	90			D_4	86	
D_5	83			D_5	83	
E_1	86	E_1	80	E_1	85.5	
E_2	80	E_2	81	E_2	81	
E_3	81	E_3	79	E_3	80	
E_4	78			E_4	71	
E_5	83			E_5	84.5	

Near field Sound Pressure Level measurements of the tram;
SLM set at slow – external filter
125 Hz octave band.

Left Side		Top of the Tank	
Position	SPL (dB)	Position	SPL (dB)
A_1	86	A_1	76
A_2	83	A_2	73
A_3	71	A_3	83
		A_4	76
		A_5	73
B_1	88	B_1	78.5
B_2	87	B_2	87.5
B_3	78.5	B_3	84
		B_4	86
		B_5	79.5
C_1	90	C_1	85.5
C_2	93	C_2	91.0
C_3	83	C_3	92
		C_4	90
		C_5	86
D_1	85.5		
D_2	86.5		
D_3	83		
E_1	76.5		
E_2	82.5		
E_3	80		

Sticking the microphone down inside the transformer as you face the front door in the left hole S.P.L reading 96 dB

Sticking the microphone in the right hole and S.P.L reads 96.5 dB.

Measurement with S.L.M.
125Hz octave band
Meter set at slow - external filter.

Distance from the center of the Transformer along 0°	6" off the ground dB	1½' off the ground dB	3' off the ground dB	6' off the ground dB
10 ft	79.5	77.5	76	70
20 "	75	74	73.5	69
40 "	70	71	72	69

SPL readings around the transformer tank at a 10 ft radial distance from the tank center.

Angular Position (degree)	dB	Angular Position (degree)	dB	Angular Position (degree)	dB
0°	79.5	0	79.5	22.5°	77.5
-15°	77	-15	77.3	45°	75
-45°	75.5	-45	76.5	67.5	74.2
-90	74	-67.5	74	90	74.5
-135	78	-90	73.5	112.5	77
-180	79	-112.5	77	135	78.2
-180	78	-135	78.5	157.5	78.7
-135	77	-157.5	79	180	78
-90	74	-180	78.5		
-45	76				
0	78.5				

SPL readings around the transformer tank at 10 ft radial distance from the tank center.

125 Hz Octave band.

Meter set at slow - external filter

6" off the ground.		3' off the ground.
Angular Position degree	dB	dB
0°	77.5	74.5
15	77	74
30	76.5	73.5
45	75.5	71
60	75	70.5
75	73.5	70
90	74	69
105	76.5	72
120	78	72
135	78	73
150	79	74
165	79	74
180	77	73
195	78	73
210	79	74
225	79	73
240	77.5	72
255	74	71
270	73	70.5
285	73	71
300	73.5	72.5
315	76.5	73.5
330	77	74
345	78.5	74
360	79	74

SPL readings around the transformer tank at 20 ft radial distance from the tank center.

	6" off the ground	3' off the ground
Angular Position (degrees)	dB	dB
0	74	73
15	74	73
30	74	72
45	72	70
60	71	69
75	71	68
90	72	69
105	72	72.0
120	72	71
135	74.5	72
150	74.0	72
165	74.5	72
180	72	70 , 72
195	73.5	73.5
210	71	73
225	73	72
240	73	72
255	70	71
270	69	69.5
285	69	70
300	71	70
315	71	70
330	73	71
345	74	73
360	74	73

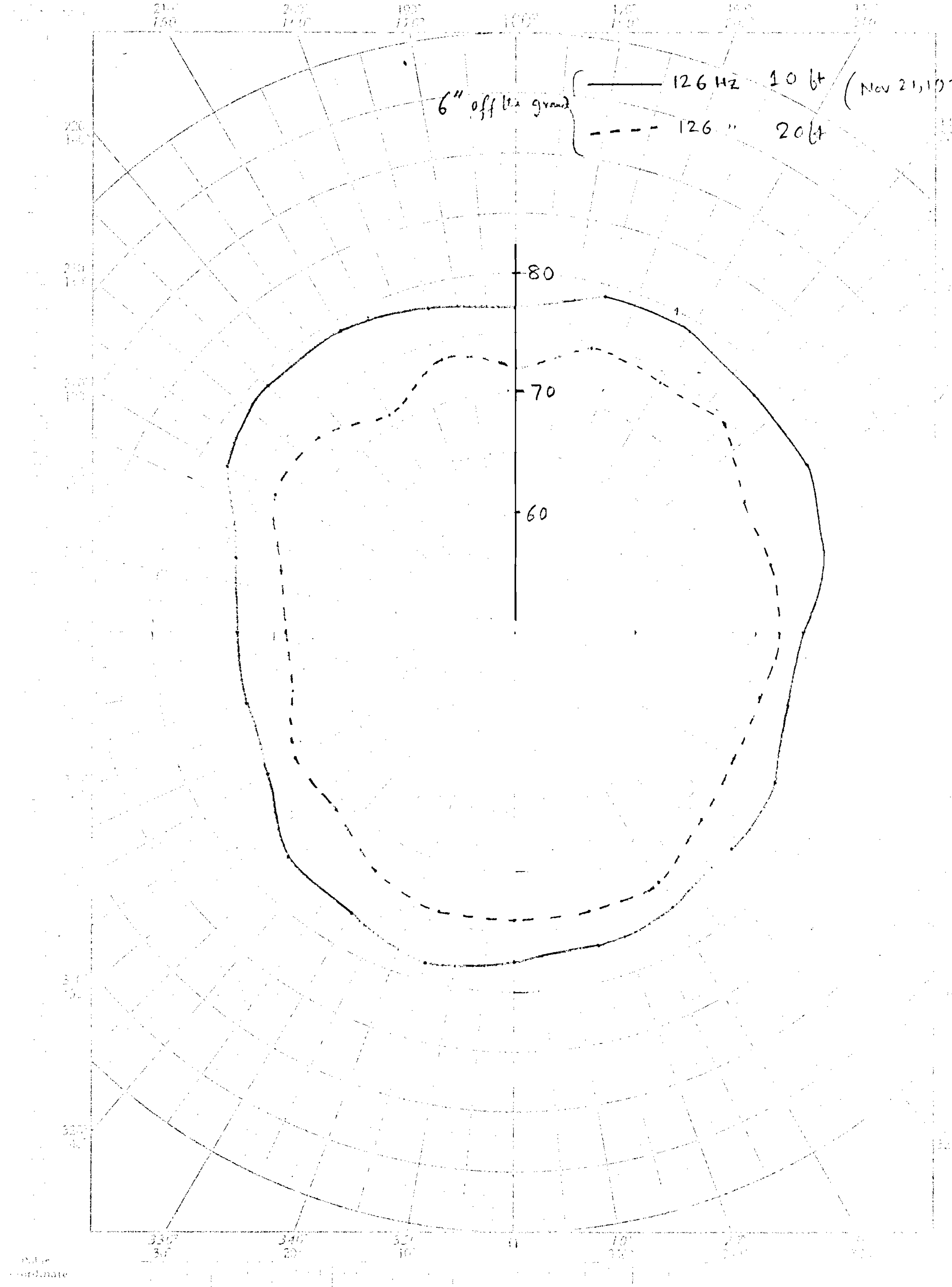
Rechecking the near field data: (See earlier pictures).

Front face	dB	Back Side	dB
A_1	93	A_1	88
C_3	88	C_3	97.5
E_5	83	E_5	81.0

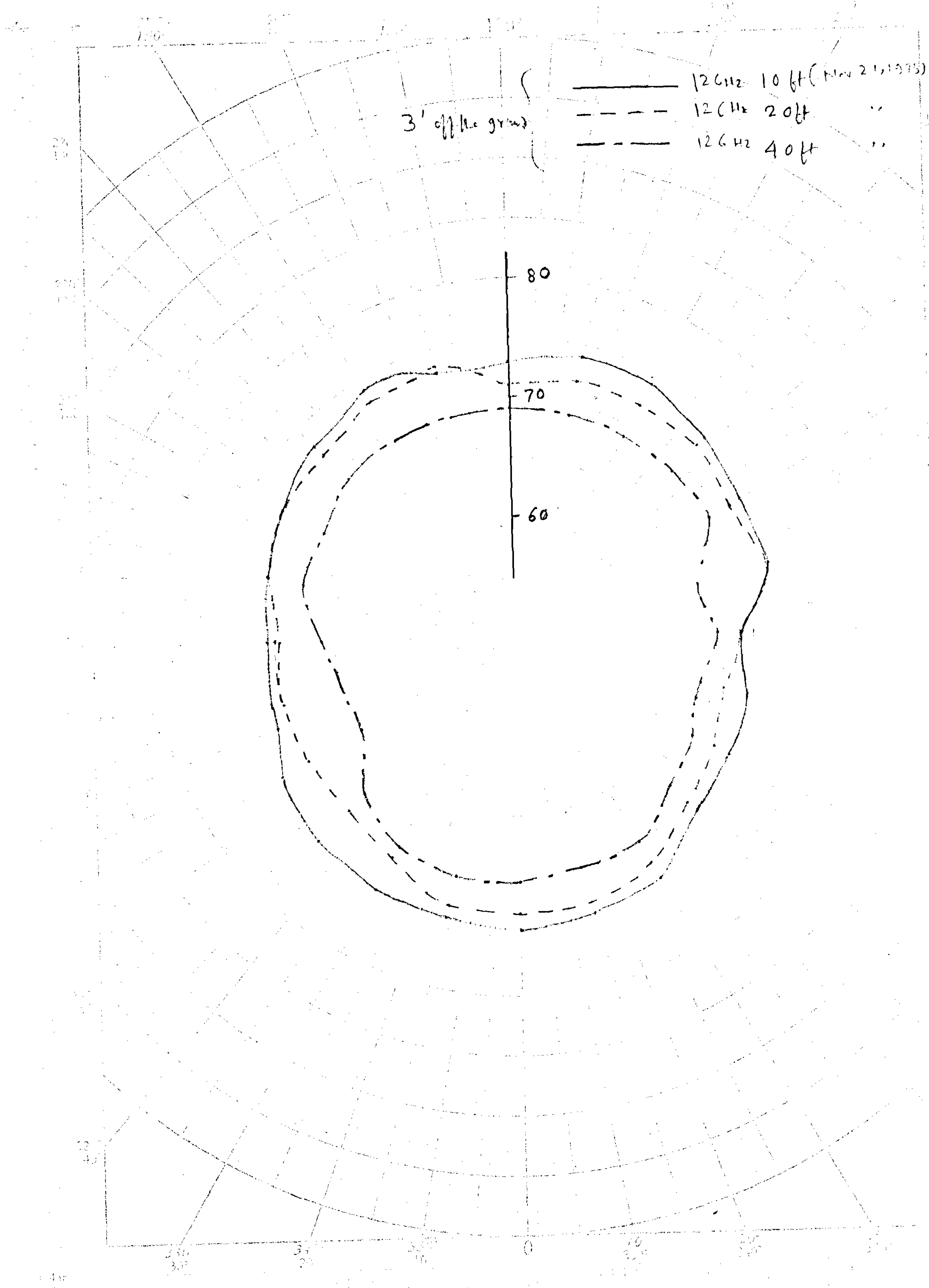
Right Side	dB	Left Side	dB
A_1	77.5	A_1	84.5
C_2	94.0	C_2	92.0
E_3	78.0	E_3	81

SPL reading around the transformer tank at 40 radial distance from the tank center. (3 ft. off the ground

Angular Position (degree)	dB.	Angular Position (degree)	dB
0	70.5	-195	69
-15	70.5	-210	69
-30	70	-225	69
-45	68	-240	69
-60	65	-255	66
-75	65	-270	67
-90	66	-285	66
-105	68	-300	67
-120	68	-315	68
-135	69	-330	70
-150	69	-345	70
-165	69	-360	72
-180	69		



6" off the ground
126 Hz 10 ft
126 " 20 ft
80
70
60



3' off the ground
12 GHz 10 ft (Nov 21, 1975)
12 GHz 20 ft ''
12 GHz 40 ft ''
80
70
60
0

E-25-656

GEORGIA INSTITUTE OF TECHNOLOGY
ATLANTA, GEORGIA 30332

SCHOOL OF
MECHANICAL ENGINEERING

/9

November 12, 1975

Mr. R.A. Nelson, Manager
Advanced Development Engineering
Building No. 2, Laboratory
Medium Transformer Department
General Electric Company
Redmond Circle
Rome, Georgia 30161

Dear Mr. Nelson:

This letter constitutes a progress report on the General Electric sponsored project on "Propagation of Noise from Electric Transformers" being conducted by Georgia Tech.

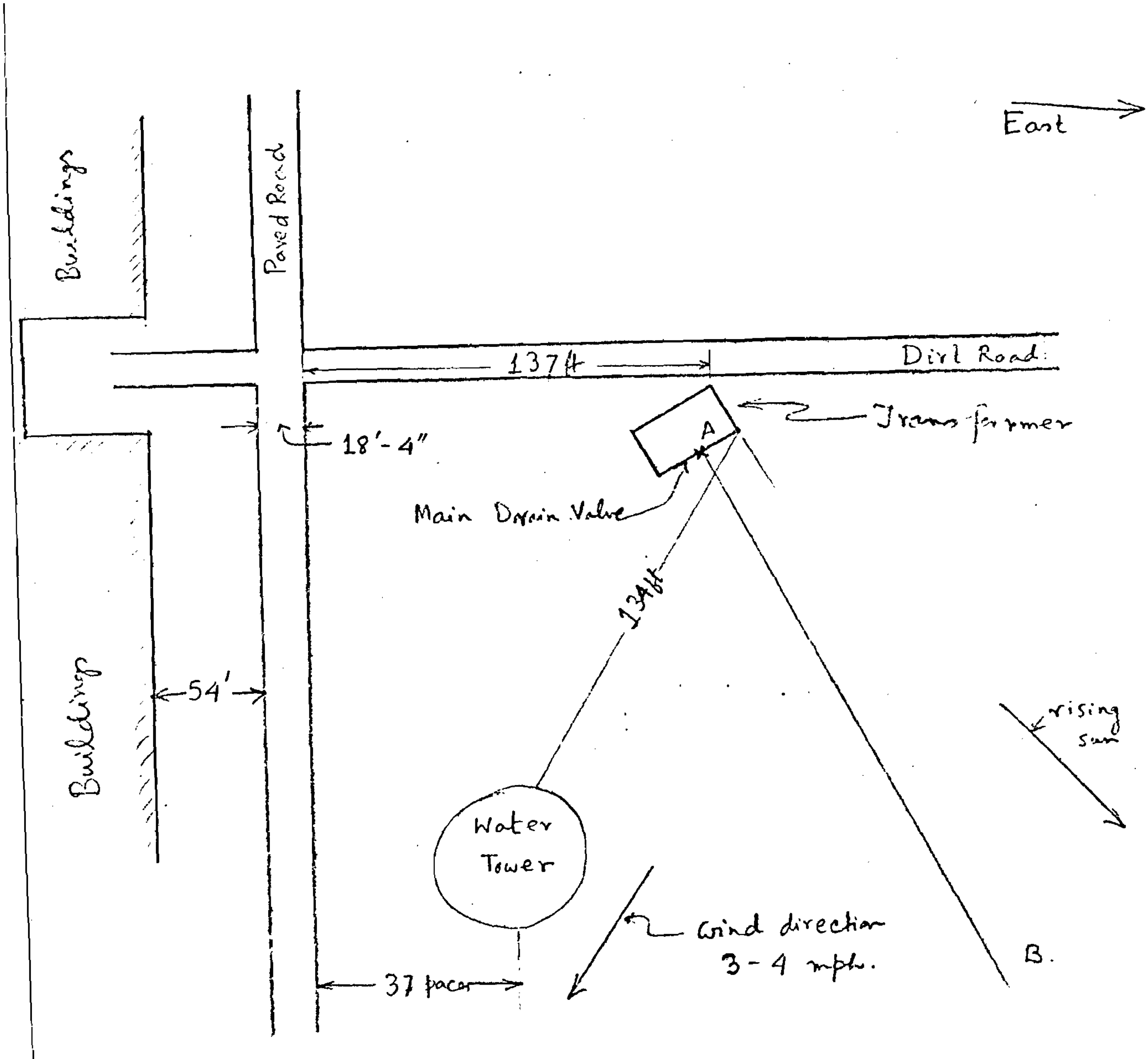
Time expended on subject project to date has consisted of review of literature on transformer noise, technical discussions and experiment planing with Mr. G. Usry in Rome, field trips and experiments at the General Electric plant on noise from a simulated transformer, analysis of the data from these field experiments, and the development of a tentative theory for relating near field sound pressure levels to far field experiments.

A preliminary account of the results of our field measurements on Friday, Oct. 24 and Monday, Oct. 27, is attached here.

Cordially yours,

Allan D. Pierce
Professor

ADP/ncs


East
Buildings
Paved Road
Dirt Road
137 ft
Transformer
A
18'-4"
Main Drain Valve
134 ft
Buildings
54'
rising sun
Water Tower
Wind direction
3-4 mph.
B.
37 paces

The experiment started, at G.E Plant in Rome, Georgia to take the sound pressure level readings of a medium size transformer, around 12-00 noon Friday Oct 24, 1975.

The measurements were taken in two halves — a) in the morning and b) in the afternoon. In the morning the measurements were taken with the sound level meter - type 2204. This included the s pressure level data along the line AB (line AB is ⊥ to the front face of the transformer; the face where the main drain valve is located, is called the front face) at 10, 20, 40, 80, 160 & 320 ft. distances from t center of the transformer at two different heights — half (½) ft. off the ground and three (3) ft. off the ground. These measurements were taken at both 125 Hz octave band filter and 250 Hz octave band filter (o.b.f. The sound pressure level (S.P.L.) were measured at a 40 ft. radial distance, and 3 ft. off the ground, from the center of the transformer tank for both 125 and 25 octave band filter to obtain the directivity pattern of the source.

The ambient noise for different dB scales and for different octave band filters were recorded prior to the starting of the experiment.

In the afternoon the experiment continue with G.E.'s Spectral Dynamics SD 360. The pressure measurements along the line AB, at distances of 10, 20, 40, 80, 160, 270 and 320 ft. away from the transformer (at both ½ ft. and 3 ft. off the ground) were taken with the SD 360. The signal frequency was at 120 Hz during the experiment with SD 360.

How to read SD 360 to get the final result in dB?

Example

The SD 360 is first calibrated and set at Test Condⁿ 100 dB = 0 . . . . . . Attn = 26.

During the expt. the SD 360 will show a no. corresponding to the transformer noise for each position. If this no. is -ve (this -ve number has been denoted by only its magnitude in all the tables), it is subtrac[ted] from the test Condⁿ (i.e, from 100 dB in this case) to get the actual S.P.L in dB. If the no. is + (this no. has been denoted with +ve sign in the tables), it has to be added to the test Condⁿ (100 dB in th[is] case) to get the actual S.P.L in dB

Friday Oct 24, 1975 — 12:00 Noon

Ambient Noise Recording (Measurement with SLM).

Network Switch Position	Sound Pressure Level
Linear (flat)	76 dB.
'A'	58 dB A
C	74 dB C

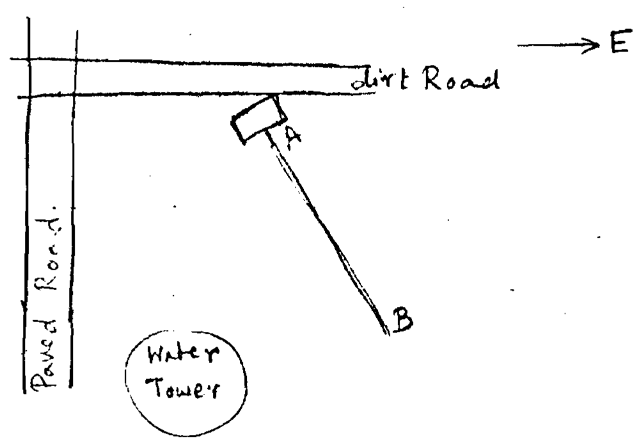
External Filters: (octave band filters) (HZ)	Sound Pressure Level (dB)
31·5	69
63	72
125	66
250	58
500	54
1000	51
2000	48
4000	40
8000	30

Friday Oct 24, 1975

Measurements with SLM.
125 HZ octave band filter

Distance from the center of the Transformer along AB (ft.)	Sound Pressure Level (dB).	Repeated measurements
1/2 ft. off ground.		
10	95·5	
20	92·0	
40	87·5	
80	82·5	82·5
160	71·5	72·5
320	71·5	
3 ft. off ground.		
10	92	
20	89	
40	85·5	
80	81·0	
160	71·5	
320	70·0	

← repeated measuremen[ts]



Oct 24, 1975

Sound Pressure measurement with the Sound Level Meter.

125 Hz octave band filter.

SPL around the transformer tank at a 10 ft radial distance from the tank center.

All results are 3 ft off ground.
(Consider the line AB as Zero (0) degrees (°) line)

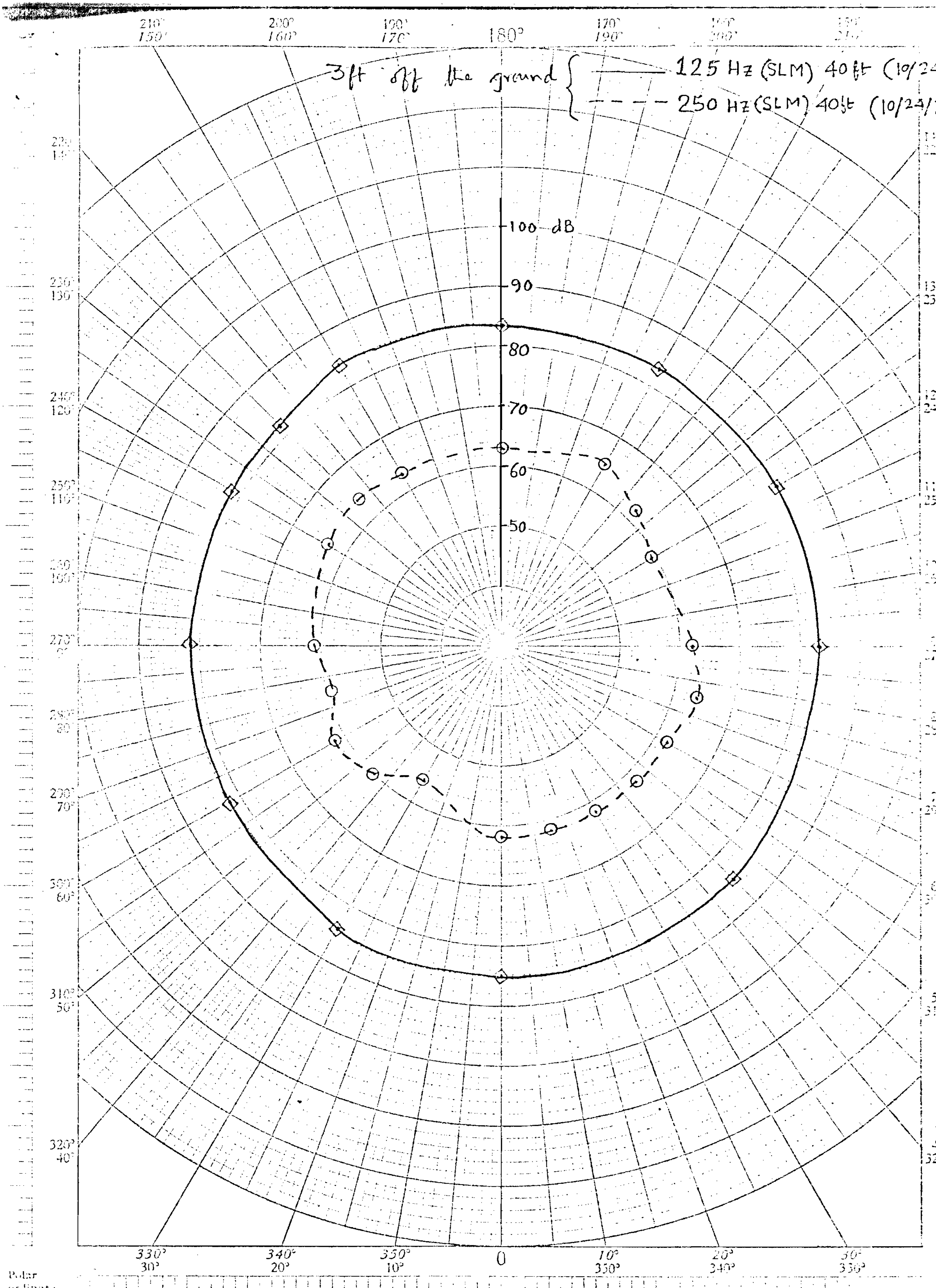
Angular Position (in degree)	Sound Pressure Level (dB)
0	85
45	85
90	83·5
120	83
150	83
180	83·5
210	84
225	82
240	81·5
270	81·5
300	82·0
330	84·5

SPL measurements with the SLM.
250 Hz octave band filter.

Distance from the Center of the Transformer tank along AB (ft)	Sound Pressure Level (dB)
(1/2) ft off the ground.	
10	77
20	70
40	63
80	58
160	56

SPL around the transformer tank at a 40 ft. radial distance from the tank center.
250 Hz octave band filter.
All results are 3 ft. off the ground.
(Consider the line AB as zero degree (0°) line.)

Angular Position (degree)	Sound Pressure Level (dB)	Angular Position (degree)	Sound Pressure Level (dB)
0	62		
15	62	210	63
30	62	225	64
45	62	240	63
60	62	270	61
75	64	285	59
90	62	300	62
120	59	315	60
135	62	330	56
150	65		
180	63		



3ft off the ground
125 Hz (SLM) 40ft (10/24
250 Hz (SLM) 40ft (10/24/
100 dB
90
80
70
60
50
180°
0

Measurements with Spectral Dynamics SD360.
Test Condition Reference ⇒ 100 dB = 0.

[One has to subtract the no. (if only the magnitude is given ; if the magnitude with a +ve sign is given then one has to add that no) that one gets from SD 360 from 100 dB [Note in this case Test Cond^n Reference ⇒ 100 dB = 0] to get the actual S.P.L in dB.]

[The SD 360 was calibrated at 500 Hz frequency. Frequency Range is from 0 to 1000 HZ]

Data for measurements of Sound Pressure Level, along the line AB at different distances and different heights:-
Frequency generator put on <u>120</u> Hz.
(Time 2-40 PM ; Ambient Temp 26°C).

Distance (ft)	Height (from Ground) (ft)	SD Reading (down)↓	dB (100 − SD) (1)	SD Reading (up)↑	dB (100 − S.D) (2)	Avg dB ((1)+(2))/2
10	½	+0·5	100·5	2·2	97·8	99·15
20	↓	1·5	98·5	4·2	95·8	97·15
40		6·2	93·8	9·1	90·9	92·35
80		10·4	89·6	13·2	86·8	88·2
160		20·2	79·8	19·9	80·1	79·95
270		23·7	76·3	23·0	77·0	76·65
320		25·6	74·4	25·6	74·4	74·4
10	3	1·1	98·9	4·0	96	97·45
20	↓	3·6	96·4	5·2	94·8	95·6
40		8·3	91·7	9·4	90·6	91·15
80		11·7	88·3	13·8	86·2	87·25
160		20·4	79·6	21·3	78·7	79·15
270		23·2	76·8	26·1	73·9	75·35
320		27·7	72·3	27·7	72·3	72·3

Time 3·20 PM. Oct 24, 1975.

SD 360

Data for Measurement of SPL, around the transformer tank at a 80 ft radial distance from the tank center.

All results are for 3 ft. off ground.

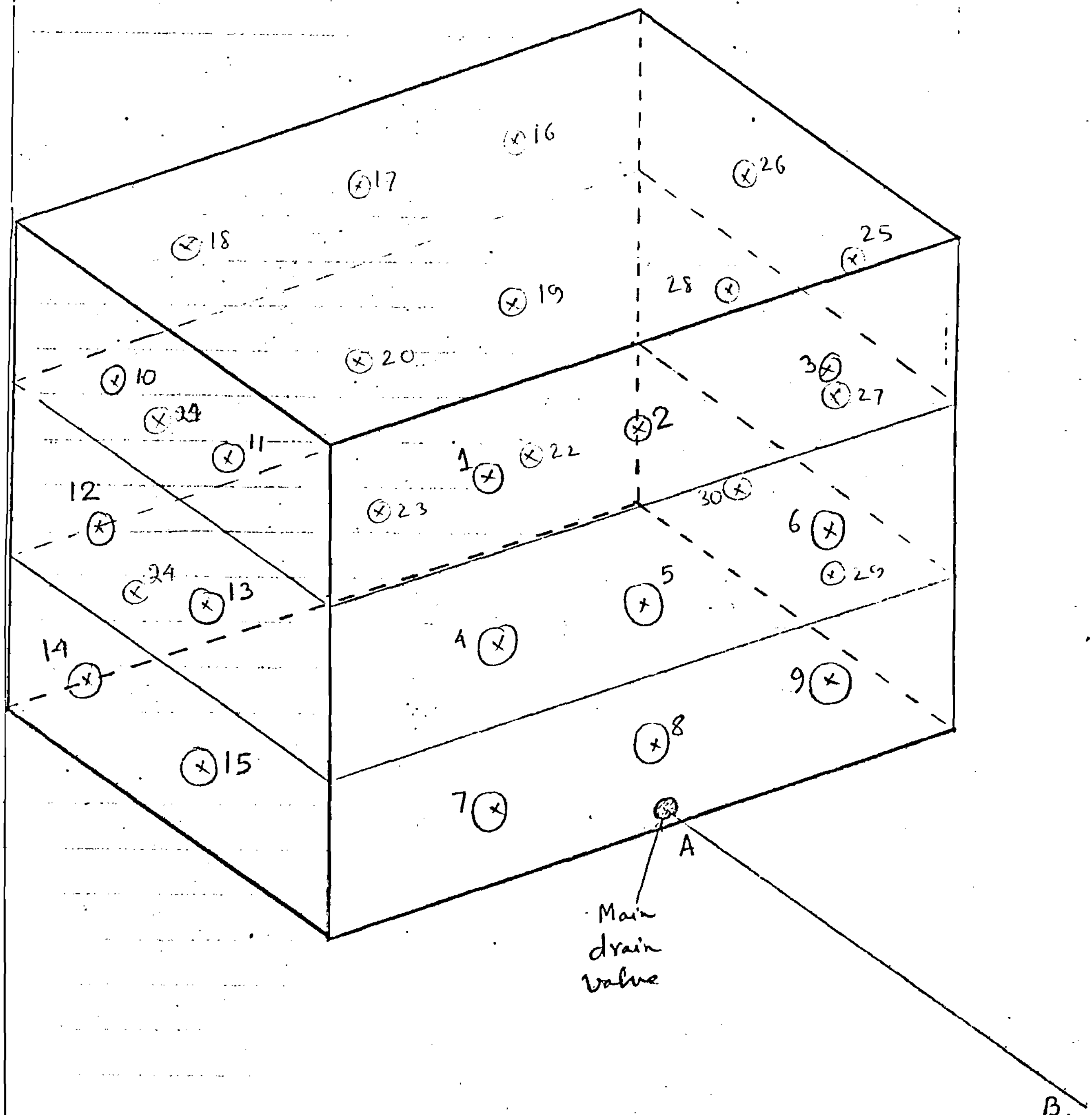
Test Condition Reference ⇒ 100 dB = 0

Frequency generator put on 120 Hz.

(Consider the line AB as a zero degree (0°) line).

Angular position (in degree °)	SD Reading	dB (100 − SD)	Angular position (in degree °)	SD Reading	dB (100 − SD)
0	16·7	83·3	187·5	10·5	89·5
7·5	15·0	85	195	11·4	88·6
15	15·3	84·7	202·5	11·6	88·4
22·5	14·6	85·4	210	11·9	88·1
30	15·3	84·7	217·5	11·9	88·1
37·5	16·4	83·6	225	12·0	88
45	18·3	81·7	232·5	13·5	86·5
52·5	16·7	83·3	240	13·0	87
60	18·0	82	247·5	13·2	86·8
67·5	16·5	83·5	255	12·9	87·1
75	15·3	84·7	262·5	14·2 }	85·8
82·5	15·3	84·7	270	14·8 }	85·2
90	15·2	84·8	277·5	15·0	85
97·5	15·0	85	285	17·0	83
105	14·1	85·9	292·5	15·6	84·4
112·5	13·5	86·5	300	16·4	83·6
120	13·3	86·7	307·5	16·0	84
127·5	12·7	87·3	315	16·3	83·7
135	12·0	88	322·5	17·0	83
142·5	11·7	88·3	330	15·9	84·1
150	11·6	88·4	337·5	15·8	84·2
157·5	11·1	88·9	345	15·0	85
165	10·2	89·8	352·5	15·0	85
172·5	10·3	89·7	360	15·1	84·9
[illegible]	[illegible]	[illegible]			

The nos. written in pen are with back side.



Time 3·20. PM. Oct 24, 1975.

SD 360

Data for Measurement of SPL, around the transformer tank at a 80 ft radial distance from the tank center.

All results are for 3 ft. off ground.

Test Condition Reference ⇒ 100 dB = 0.

Frequency generator put on 120 Hz.

(Consider the line AB as a zero degree (0°) line).

Angular position (in degree°)	SD Reading	dB (100 − SD)	Angular position (in degree°)	SD Reading	dB (100 − SD)
0	16·7	83·3	187·5	10·5	89·5
7·5	15·0	85	195	11·4	88·6
15	15·3	84·7	202·5	11·6	88·4
22·5	14·6	85·4	210	11·9	88·1
30	15·3	84·7	217·5	11·9	88·1
37·5	16·4	83·6	225	12·0	88
45	18·3	81·7	232·5	13·5	86·5
52·5	16·7	83·3	240	13·0	87
60	18·0	82	247·5	13·2	86·8
67·5	16·5	83·5	255	12·9	87·1
75	15·3	84·7	262·5	14·2	85·8
82·5	15·3	84·7	270	14·8	85·2
90	15·2	84·8	277·5	15·0	85
97·5	15·0	85	285	17·0	83
105	14·1	85·9	292·5	15·6	84·4
112·5	13·5	86·5	300	16·4	83·6
120	13·3	86·7	307·5	16·0	84
127·5	12·7	87·3	315	16·3	83·7
135	12·0	88	322·5	17·0	83
142·5	11·7	88·3	330	15·9	84·1
150	11·6	88·4	337·5	15·8	84·2
157·5	11·1	88·9	345	15·0	85
165	10·2	89·8	352·5	15·0	85
172·5	10·3	89·7	360	15·1	84·9

SD-360

Data for measurement of SPL along the wall of the Transformer Tank.

Test condition reference ⇒ 110 dB = 0

Frequency generator put on 120 Hz

Position #	S.D Reading	dB (110 - SD)	Position #	S.D Reading	dB (110 - SD)
1	+ ·4	110·4	16	+ 2·2	97·8
2	+1·1	111·1	17	+ 3·0	97
3	+ ·6	110·6	18	+ 2·4	97·6
4	·6	99·4	19	+ ·7	99·3
5	3·3	96·7	20	+ 1·9	98·1
6	1·6	98·4	21	+ 1·1	98·9
7	12·0	88·	22	9·4	90·6
8	5·4	94·6	23	3·9	96·1
9	11·2	88·8	24	7·1	92·9
10	1·5	98·5	25	1·9	98·1
11	2·0	98	26	1·1	98·9
12	3·2	96·8	27	3·8	96·2
13	4·5	95·5	28	2·0	98
14	14·0	86·	29	13·9	86·1
15	13·7	86·3	30	16·8	83·2

Time 4-20PM. Oct 24, 197[illegible]

SD 360

Data of SPL, around the transformer tank at a 40 [illegible] radial distance from the tank center.

All results are for 3 ft off ground.

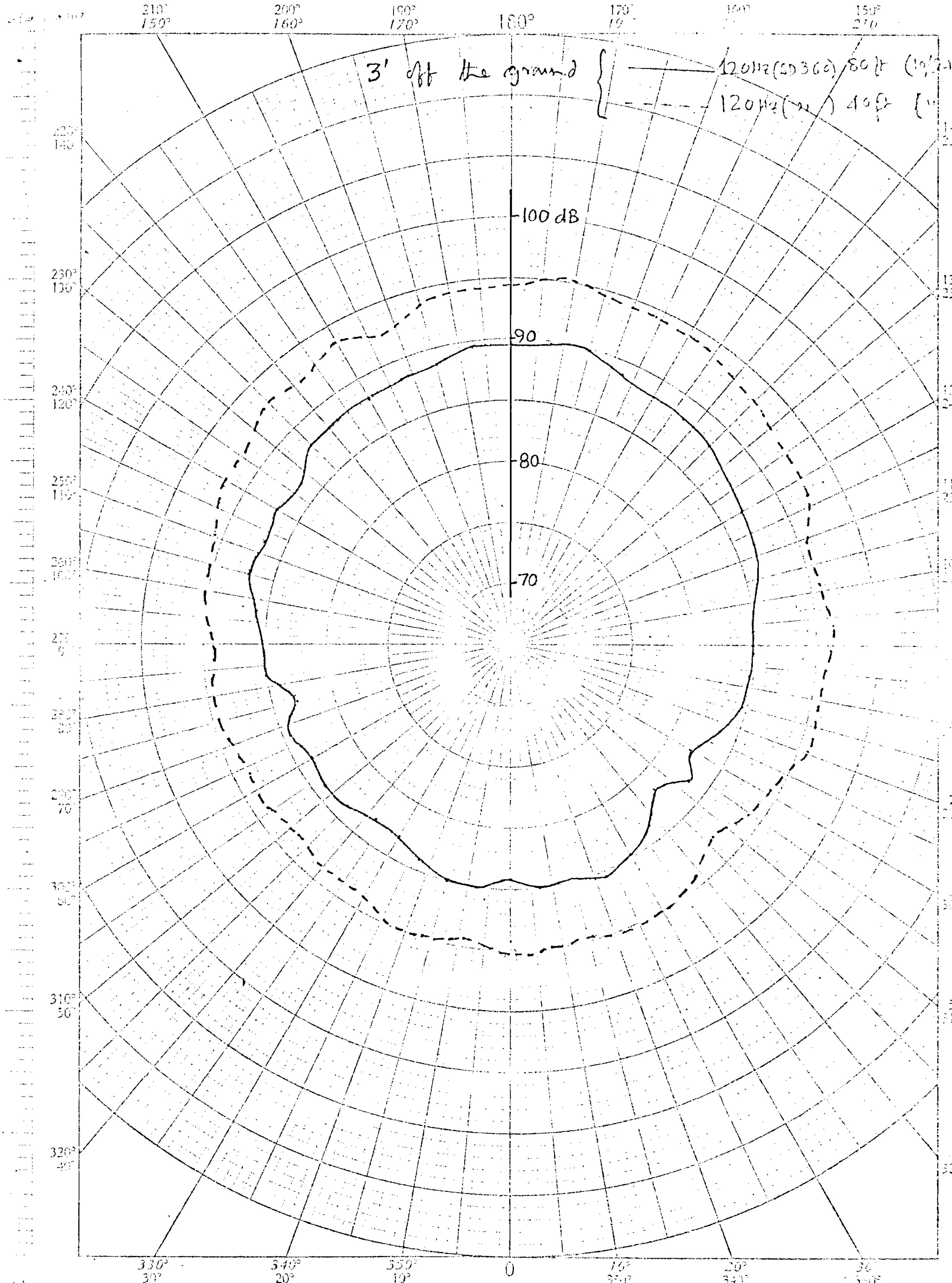
Test Condⁿ Reference ⇒ 100 dB = 0. ;
Frequency generator put on 120 Hz ; Consider line AB as a 0° li[illegible]

Angular Postion (degree °)	SD Reading	dB (100 - SD)	Angular Position (degree °)	SD Reading	dB (100 - SD)
0°	10·7	89·3	187·2	5·7	94·3
7·8	10·1	89·9	195	6·3	93·7
15·6	10·3	89·7	202·8	7·7	92·3
23·4	9·6	90·4	210·6	6·4	93·6
31·2	10·0	90	218·4	7·7	92·3
39	10·9	89·1	226·2	7·2	92·8
46·8	12·2	87·8	234	8·3	91·7
54·6	11·1	88·9	241·8	8·1	91·9
62·4	10·4	89·6	249·6	9·7	90·3
70·2	9·2	90·8	257·4	9·8	90·2
78	9·4	90·6	265·2	10·3	89·7
85·8	9·1	90·9	273	10·9	89·1
93·6	8·6	91·4	280·8	10·6	89·4
101·4	9·3	90·7	288·6	10·9	89·1
109·2	9·4	90·6	296·4	11·3	88·7
117	7·9	92·1	304·2	11·1	88·9
124·8	7·6	92·4	312	11·8	88·2
132·6	7·0	93	319·8	11·2	88·8
140·4	6·5	93·5	327·6	11·2	88·8
148·2	5·8	94·2	335·4	10·1	89·9
156·0	5·7	94·3	343·2	10·1	89·9
163·8	5·5	94·5	351	10·6	89·4
171·6	4·7	95·3	358·8	9·6	90·4
179·4	5·6	94·4			

4 Ambient Readings (3 ft off ground)

Radial Distance 40' from transformer.
Reference ⇒ 100 dB = 0.

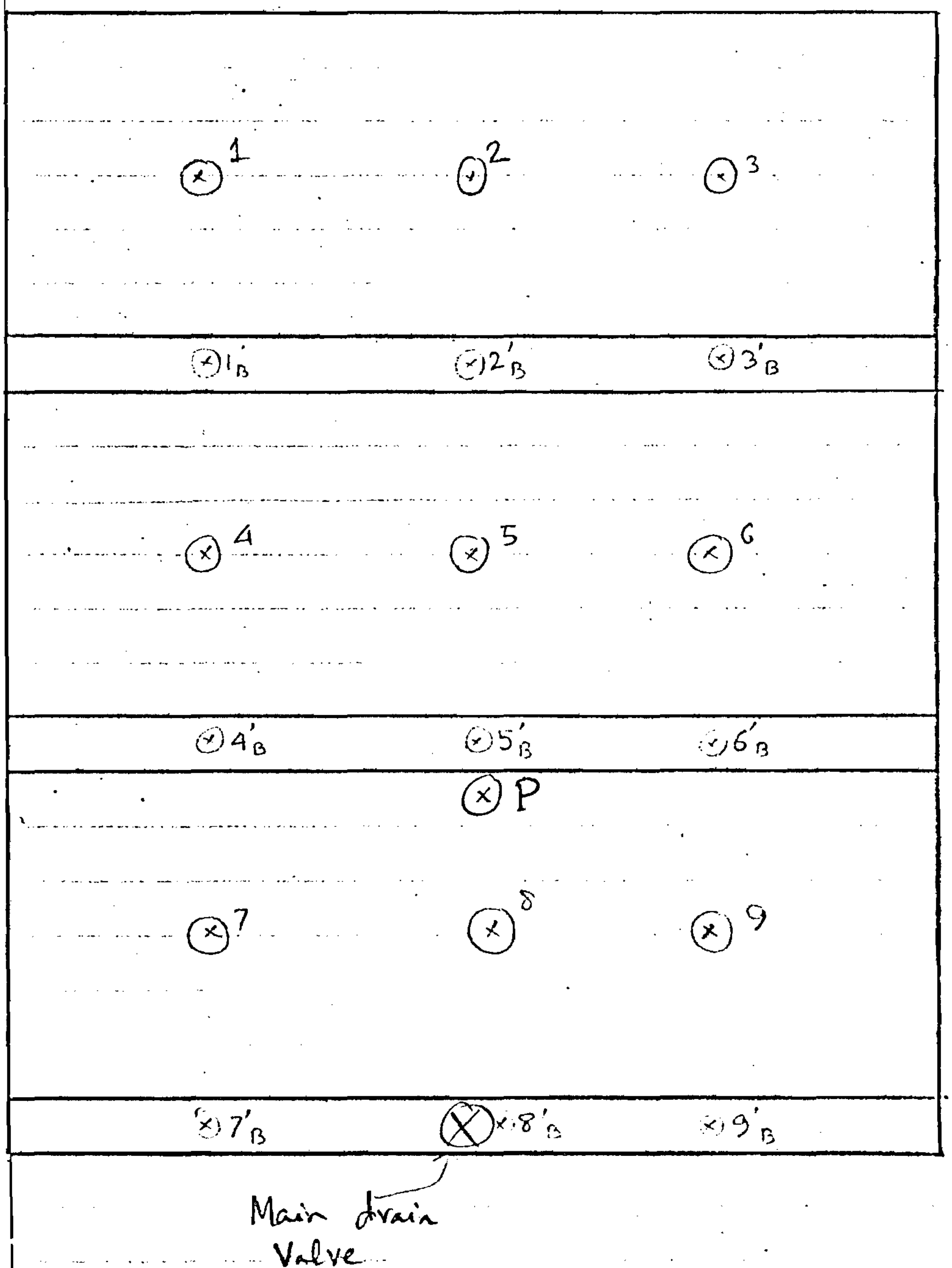
Position	SD Reading	dB=100-SD
0° → line AB.	34.4	65.6
90°	34.9	65.1
180°	34.2	65.8
270°	34.9	65.1



180°
3' off the ground
120Hz(SD360) 80ft
120Hz( ) 40ft
100 dB
90
80
70
0

Accelerometer measurements were not taken on Friday Oct 24, 1975. So, the experiment was continued on Monday Oct 27, 1975. Lot of accelerometer measurements of Sound Pressure Level measurements on all the four (4) sides of the transformer tank were taken on that day.

Front Side



127 HZ

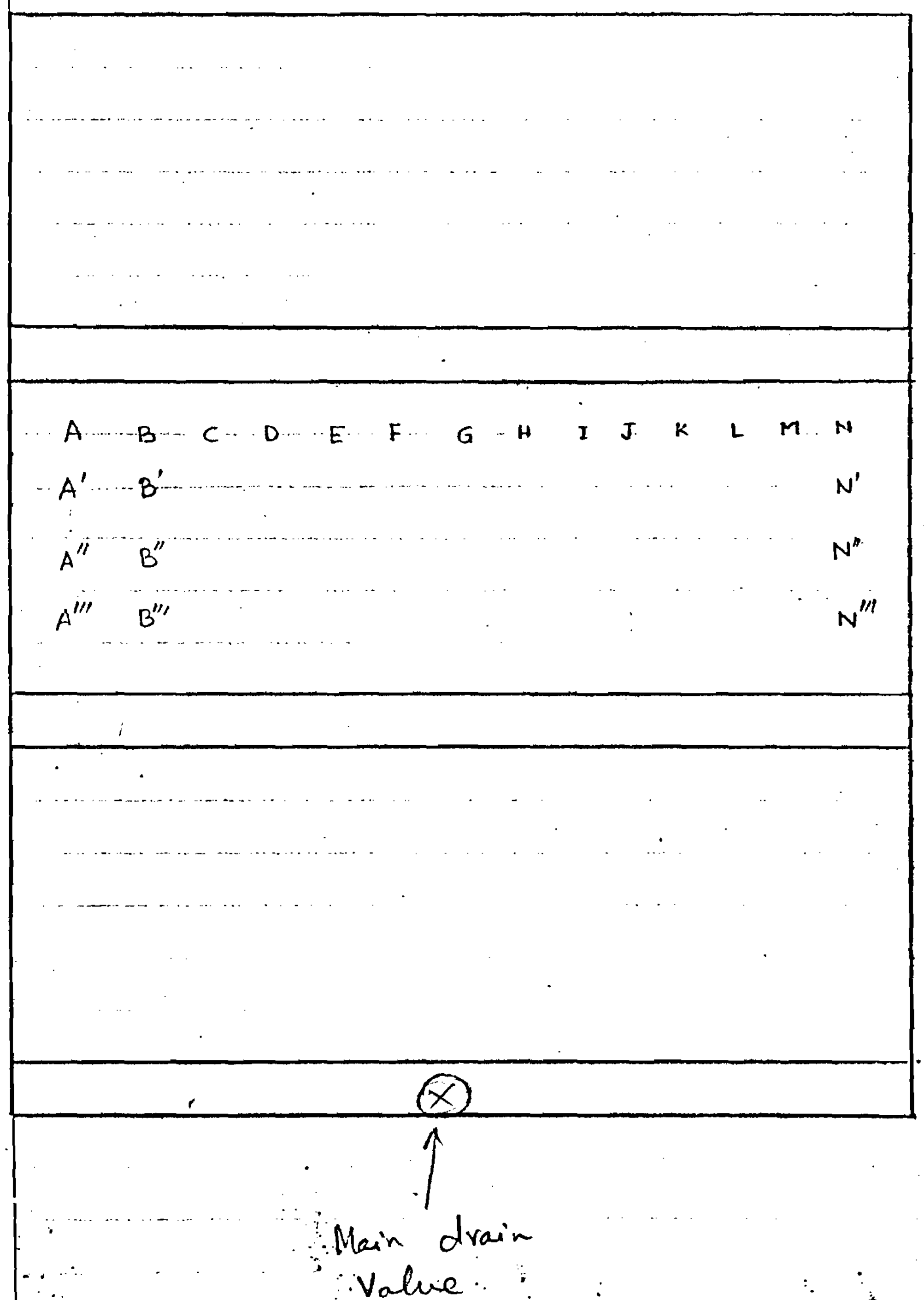
Accelerometer Measurements.
With our accelerometer (Front Side)

Position #	acceleration m/sec^2	Position #	acceleration m/sec^2
1	1.92	1	1.75
2	2.90	6	6.0
3	1.69	4	3.7
1	1.89	7	.61
1'B	1.77	8	1.32
2'B	2.62	9	1.05
3'B	1.88		
		1	1.70
1	1.82	7'B	.111
4	3.7	8'B	.124
5	5.2	9'B	.138
6	6.2		
4'B	2.57	1	1.58
5'B	4.1		
6'B	2.22		

SPL measurement by our SLM.

Position #	dB (linear)
1	91
2	93
3	90.5
1'B	87
2'B	88.5
3'B	89
4	84.5
5	83
6	89
1	90.5
4'B	85
5'B	88.5
6'B	82.5
7	75
8	74
9	73
1	90.5
7'B	Back gr
1	90.5
5	83
P	89

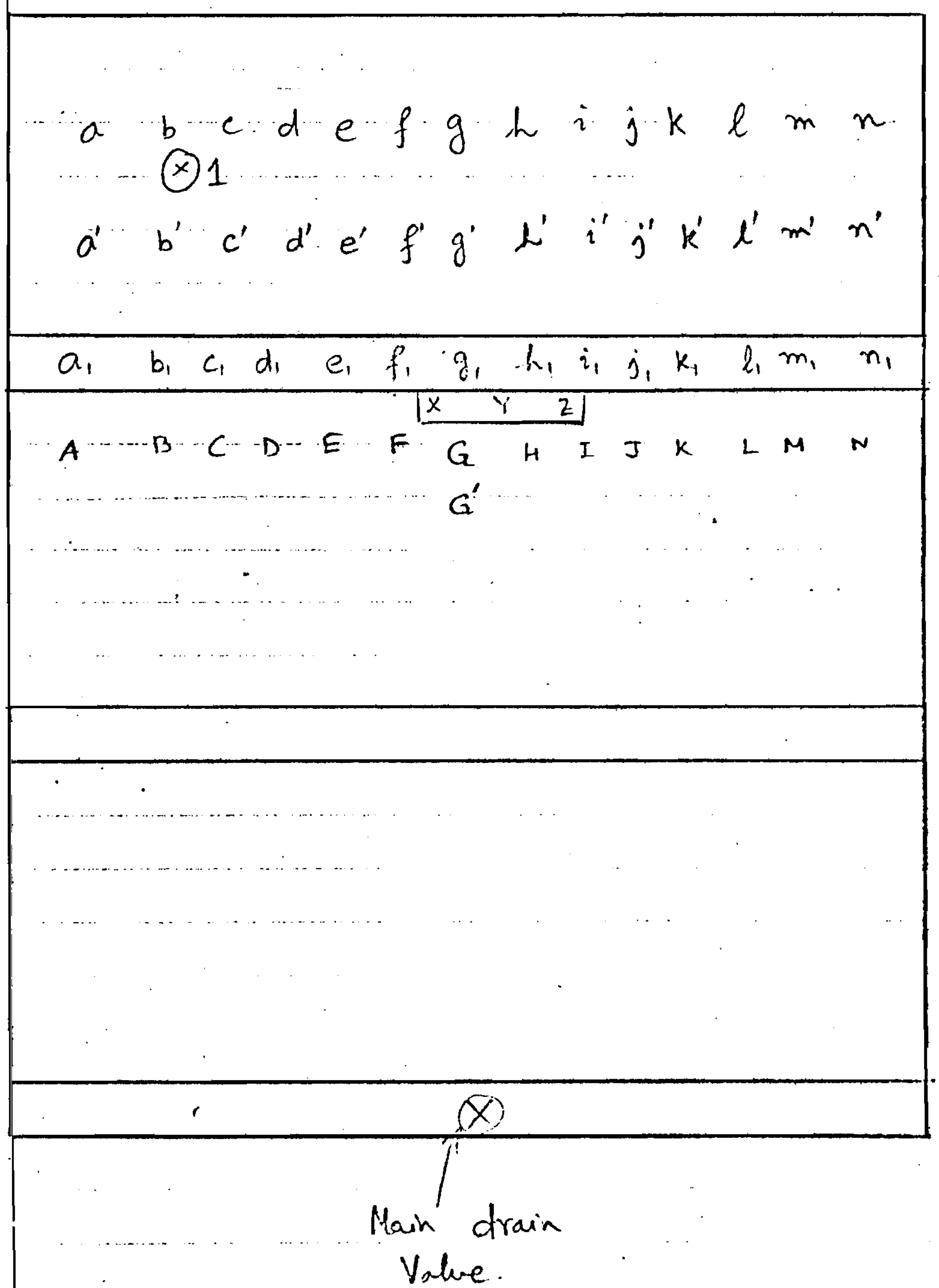
NOTE We took position # 1 as the reference. So, we checked position#1 quite often for both accel^n measurement and sound level measurement


A B C D E F G H I J K L M N
A' B' N'
A'' B'' N''
A''' B''' N'''
Main drain Value

Acceleration Measurements with our accelerometer
(for the position shown in the side figure).

Front Side 127 Hz

Position	Acceln (m/sec²)	Position	Acceln (m/sec²)	Position	Acceln (m/sec²)	Position	Acceln (m/se
A	·16	A′	·55	A″	·7	A‴	·2
B	1·5	B′	3·3	B″	3·2	B‴	·3
C	2·2	C′	4·0	C″	3·9	C‴	·5
D	1·8	D′	2	D″	·65	D‴	1·7
E	1·2	E′	·6	E″	2·5	E‴	3·1
F	·9	F′	2·8	F″	4·7	F‴	4·2
G	·7	G′	3·7	G″	6·0	G‴	4·8
H	·75	H′	2·9	H″	5·2	H‴	4·4
I	1·3	I′	1·0	I″	2·8	I‴	3·1
J	1·9	J′	2·2	J″	·58	J‴	1·8
K	2·2	K′	4·0	K″	3·2	K‴	·8
L	2·0	L′	4·5	L″	4·1	L‴	·2
M	1·4	M′	3·4	M″	3·2	M‴	·2
N	·4	N′	1·2	N″	1·0	N‴	·2



a b c d e f g h i j k l m n
1
a' b' c' d' e' f' g' h' i' j' k' l' m' n'
a1 b1 c1 d1 e1 f1 g1 h1 i1 j1 k1 l1 m1 n1
X Y Z
A B C D E F G H I J K L M N
G'
Main drain Valve.

Acceleration Measurements
(For position see the side figure)

Front Side

127 Hz

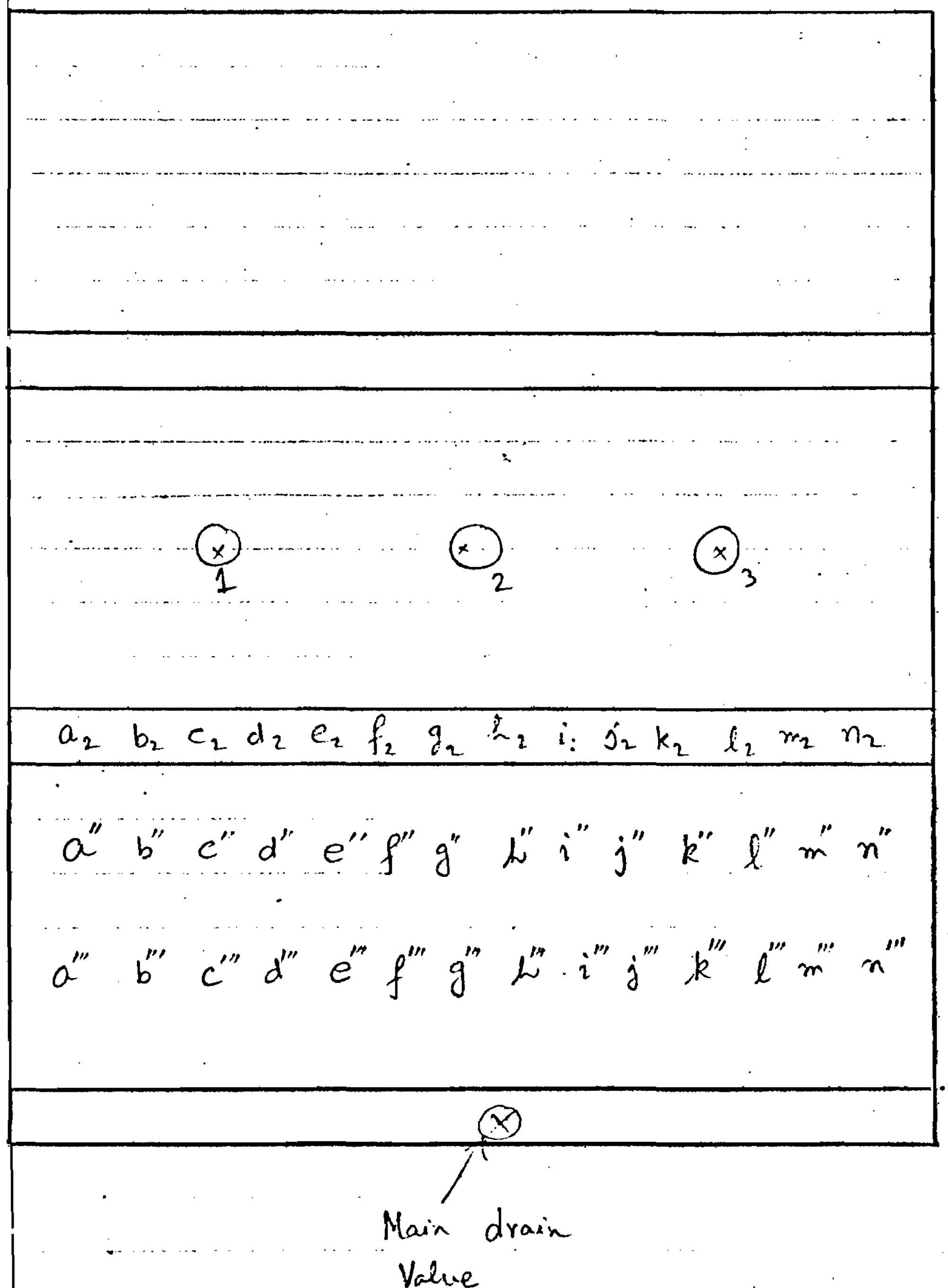
Position	Acceleration (m/sec²)	Position	Acceleration (m/sec²)	Position	Acceleration (m/sec²)
1	1·52				
a_1	·07	a	·29	a′	·078
b_1	·56	b	·165	b′	·62
c_1	1·15	c	·77	c′	1·35
d_1	1·7	d	1·1	d′	1·8
e_1	1·9	e	1·3	e′	2·1
f_1	2·0	f	1·35	f′	2·2
g_1	2·1	g	1·4	g′	2·25
h_1	2·1	h	1·25	h′	2·2
i_1	2·05	i	1·1	i′	2·1
j_1	1·9	j	·86	j′	1·85
k_1	1·5	k	·62	k′	1·5
l_1	1·1	l	·32	l′	0·95
m_1	0·7	m	·066	m′	0·43
n_1	0·18	n	·27	n′	0·04
		1	1·35	1	1·35

Measurements at some other positions.

Position	Accel^n (m/sec²)	Position	accel^n (m/sec²)
1	1·46	A	·115
X	1·65	G	·80
Y	1·8	G′	4·0
Z	1·9	1	1·40

(X, Y, Z:) 3 middle positions above

Front Side


1
2
3
a2 b2 c2 d2 e2 f2 g2 h2 i2 j2 k2 l2 m2 n2
a" b" c" d" e" f" g" h" i" j" k" l" m" n"
a"' b"' c"' d"' e"' f"' g"' h"' i"' j"' k"' l"' m"' n"'
Main drain Value

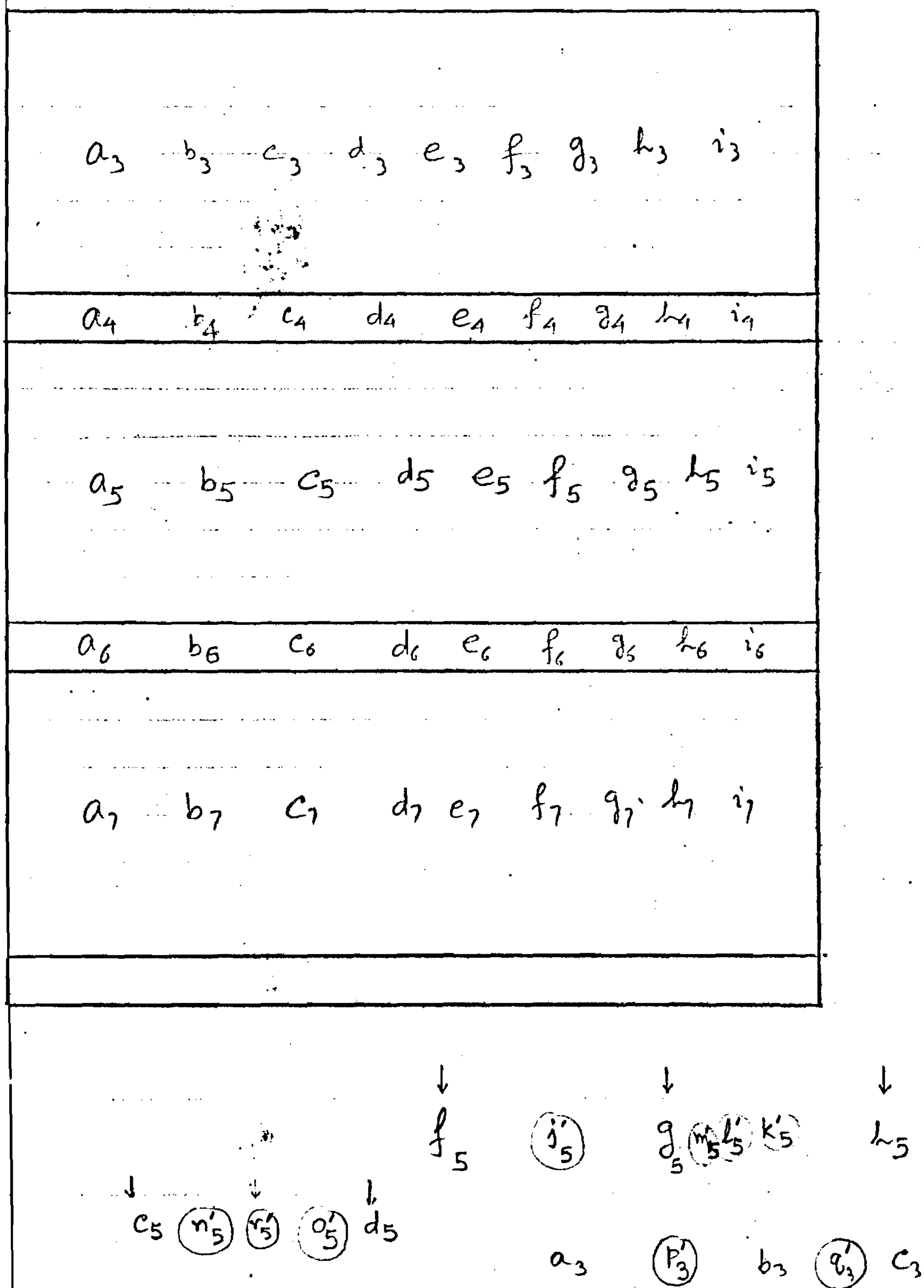
Acceleration Measurements.

(For positions See the figure)

Front Side 127 Hz

Position	acceleration. (m/sec²)	Position	acceleration (m/sec²)	Position	accelerati (m/sec²)
1	1·35				
a_2	·60	a''	·49	a'''	·05
b_2	1·3	b''	·95	b'''	·45
c_2	2·0	c''	·95	c'''	1·3
d_2	2·6	d''	·89	d'''	2·1
e_2	3·1	e''	·86	e'''	2·8
f_2	3·3	f''	·9	f'''	2·9
g_2	3·3	g''	·87 ; ·93	g'''	2·8
h_2	3·3	h''	·63 ; ·97	h''	2·7
i_2	3·0	i''	·32 ; ·88	i'''	2·6
j_2	2·5	j''	·25 ; ·97	j'''	2·15
k_2	2·0	k''	·13 ; ·78	k'''	1·65
l_2	1·4	l''	·33 ; ·68	l'''	1·1
m_2	1·1	m''	·72	m'''	·53
n_2	·5	n''	·45	n'''	·066
1	1·35	1	1·25	1	1·22

Back Side

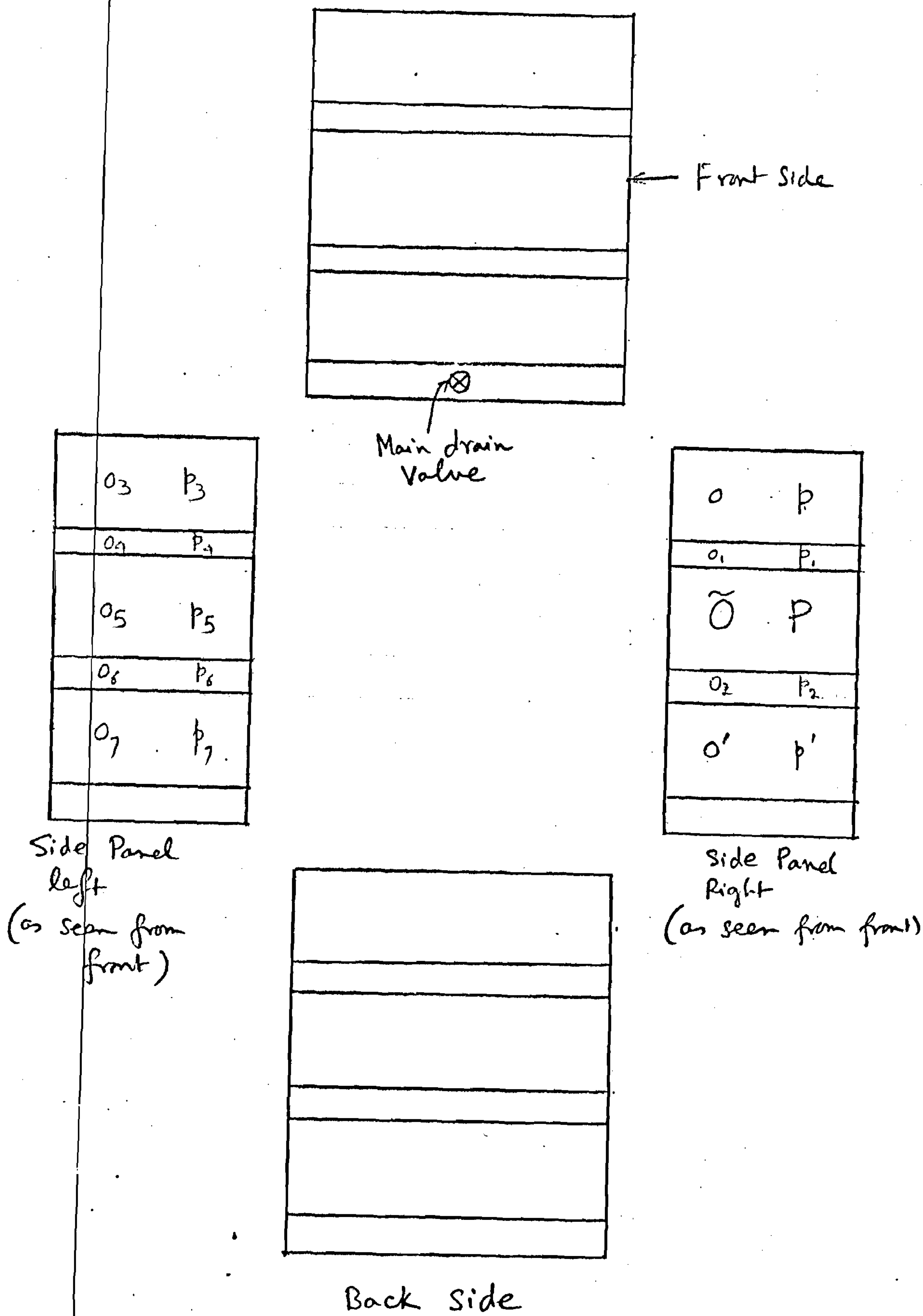


a_3 b_3 c_3 d_3 e_3 f_3 g_3 h_3 i_3
a_4 b_4 c_4 d_4 e_4 f_4 g_4 h_4 i_4
a_5 b_5 c_5 d_5 e_5 f_5 g_5 h_5 i_5
a_6 b_6 c_6 d_6 e_6 f_6 g_6 h_6 i_6
a_7 b_7 c_7 d_7 e_7 f_7 g_7 h_7 i_7
f_5 j'_5 g_5 m'_5 l'_5 k'_5 h_5
c_5 n'_5 r'_5 o'_5 d_5
a_3 p'_3 b_3 q'_3 c_3

Acceleration Measurements.
(See attached Figure).
<u>Back Side.</u>

127 Hz

Position	accel^n (m/sec²)	Position	accel^n (m/sec²)	Position	accel^n (m/sec²)	Position	accel^n (m/sec²)	Position	accel (m/
		a_5	0·88	a_5	·9	a_5	·87		
a_5	0·9	a_3	0·27	a_4	·13				
b_5	1·85	b_3	·13	b_4	·24				
c_5	1·1	C_3	·51	c_4	·68	c_6	1·1	c_7	·6
d_5	1·55	d_3	1·1	d_4	1·15				
e_5	2·98	e_3	1·5	e_4	1·36				
f_5	2·0	f_3	1·47	f_4	1·31				
g_5	0·65	g_3	1·06	g_4	1·1	g_6	1·21	g_7	1·1
h_5	0·99	h_3	·44	h_4	·6				
i_5	0·78	i_3	·14	i_4	·092				
				a_5	·9			a_5	·8
		a_3	·28						
		b_3	·11						
j'_5	1·18	q'_3	·27						
k'_5	·7	p'_3	·20						
l'_5	·58								
m'_5	·59								
j'_5	1·23								
k'_5	·7								
l'_5	·61								
r'_5	·37								
n'_5	·52								
o'_5	·78								
a_5	·88								



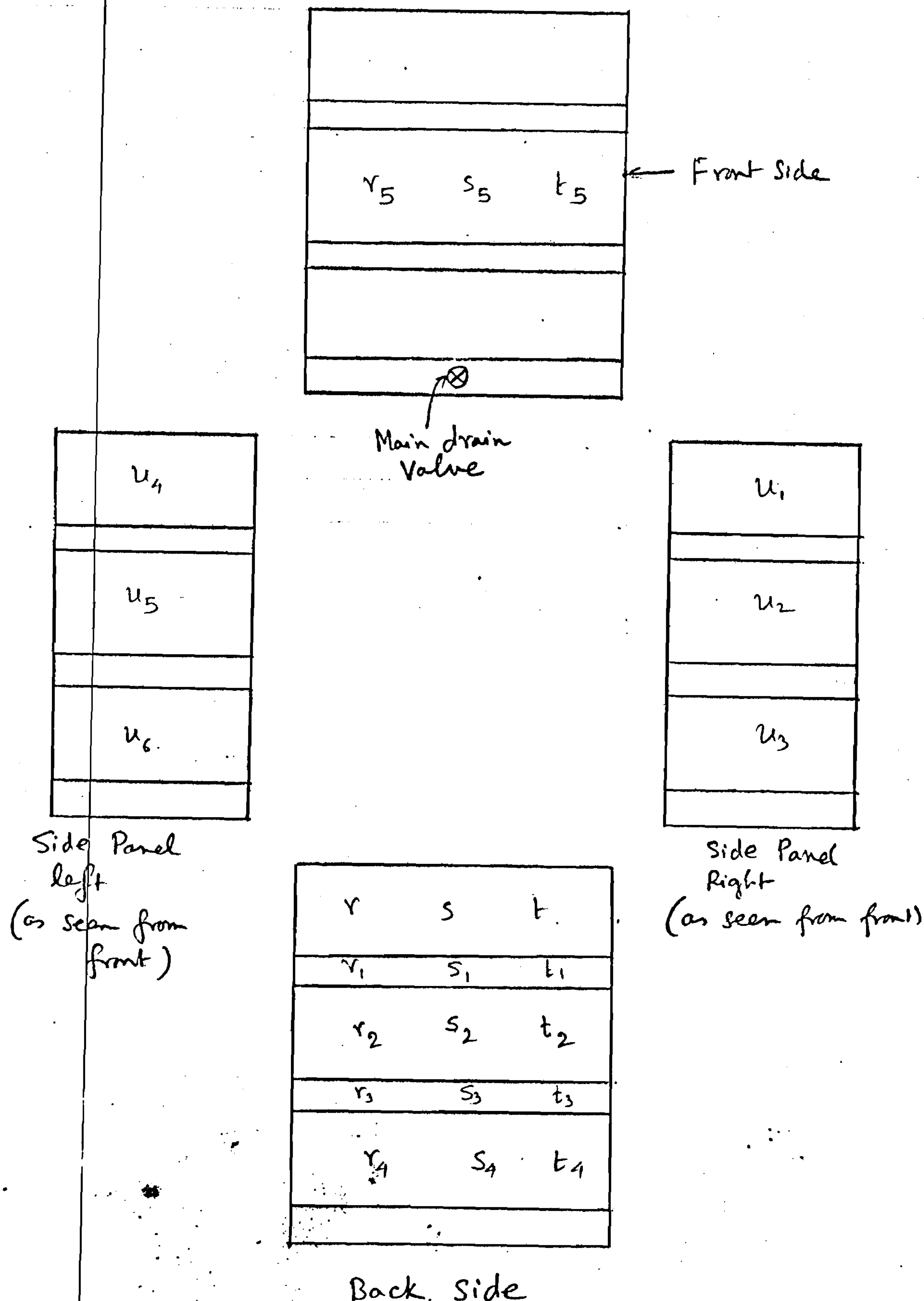
Front Side
Main drain Valve
o3 p3
o4 p4
o5 p5
o6 p6
o7 p7
Side Panel left (as seen from front)
o p
o1 p1
Õ P
o2 p2
o' p'
Side Panel Right (as seen from front)
Back Side

Acceleration Measurement

127 Hz

(See attached figure)

Side Panel Right (as seen from front)		Side Panel left (as seen from front).	
Position	accel^{n} (m/sec^2)	Position	accel^{n} (m/sec^2).
o	·21	o_3	·0095
p	·03	p_3	·18
o_1	·12	o_4	·0567
p_1	·11	p_4	·09
$\tilde{O}$	1·3	o_5	1·6
P	1·47	p_5	·64
o_2	·02	o_6	·047
p_2	·096	p_6	·038
o'	·12	o_7	·092
p'	·175	p_7	·12
o	·21	o_3	·015
1	1·2	o_4	·057



r5 s5 t5
Front Side
Main drain Valve
u4
u5
u6
Side Panel left (as seen from front)
u1
u2
u3
Side Panel Right (as seen from front)
r s t
r1 s1 t1
r2 s2 t2
r3 s3 t3
r4 s4 t4
Back Side

SPL measurement by Sound Level Meter.
(See attached figure)

127 Hz frequency.

Position	Sound Level (dB)	Position	Sound level (dB)
Back Side: r	84	Front side: r_5	81.5
s	88	s_5	86.5
t	82	t_5	88.5
r_1	83		
s_1	87.5	Right Panel: u_1	79
t_1	83.5	u_2	87.5
r_2	77	u_3	77
s_2	86.5	Left Panel: u_4	78
t_2	80.5	u_5	86.5
r_3	85	u_6	73
s_3	74		
t_3	73		
r_4	79.5		
s_4	77		
t_4	67		

Oct 27, 1975

Measurement with Spectral Dynamics SD 360.

Signal Frequency 127 Hz.
Frequency Range is from 0 to 1000 Hz.
Test Cond^n: Reference 100 dB = 0.

Microphone (1/2) ft off ground

Distance along AB (ft)	S.D. Reading	dB (100 - SD)
10'	14·9	85·1
20'	18·6	81·4
40'	23·5	76·5
80'	29·1	70·9

Oct 27, 1975

SD 360

Data for Measurement of SPL around the transf. tank at a 20 ft radial distance from the tank cente[r]. The microphone were placed ½ ft off the ground in each case.

Frequency generator put on 240 HZ.

Test Condn: Reference ⇒ 110 dB = 0

Frequency Range 0 to 1000 HZ.

(Consider line AB as a zero degree (0°) line)

Interference pt with the electric equipment (−120 to −150)

Angular Position (in degree°)	SD Reading		Avg SD Reading	dB (110 − SD)	Angular Position (in degree°)	SD Reading		Avg. SD Reading	dB (110 − S[D])
0	16·4	15·8	16·1	93·9					
−15	13·3	13·5	13·4	96·6	−195	30·6		30·6	79·4
−30	13·0	12·9	12·95	97·05	−210	33·6		33·6	76·4
−45	10·7	10·8	10·75	99·25	−225	29·2		29·2	80·8
−60	14·1	14·1	14·1	95·9	−240	23·9	23·6	23·75	86·2
−75	19·8	19·5	19·65	90·35	−255	22·0	21·5	21·75	88·2
−90	21·0	20·4	20·7	89·3	−270	23·9	24·0	23·95	86·0
−105	23·8	23·6	23·7	86·3	−285	25·0	25·2	25·1	84·9
−120	25·9	25·0	25·45	84·55	−300	22·8	22·9	22·85	87·15
−135	19·6	19·3	19·45	90·55	−315	19·0	19·4	19·2	90·8
−150	16·8	16·9	16·85	93·15	−330	15·7	15·6	15·65	94·3
−165	18·3	18·5	18·4	91·6	−345	16·7	17·2	16·95	93·[illegible]
−180	30·5	30·5	30·5	79·5	−360	16·1	15·7	15·9	94·1

WITH ONE SPK'R ONLY ≈ 82% Magnitude

Oct 27, 1975.

SD 360

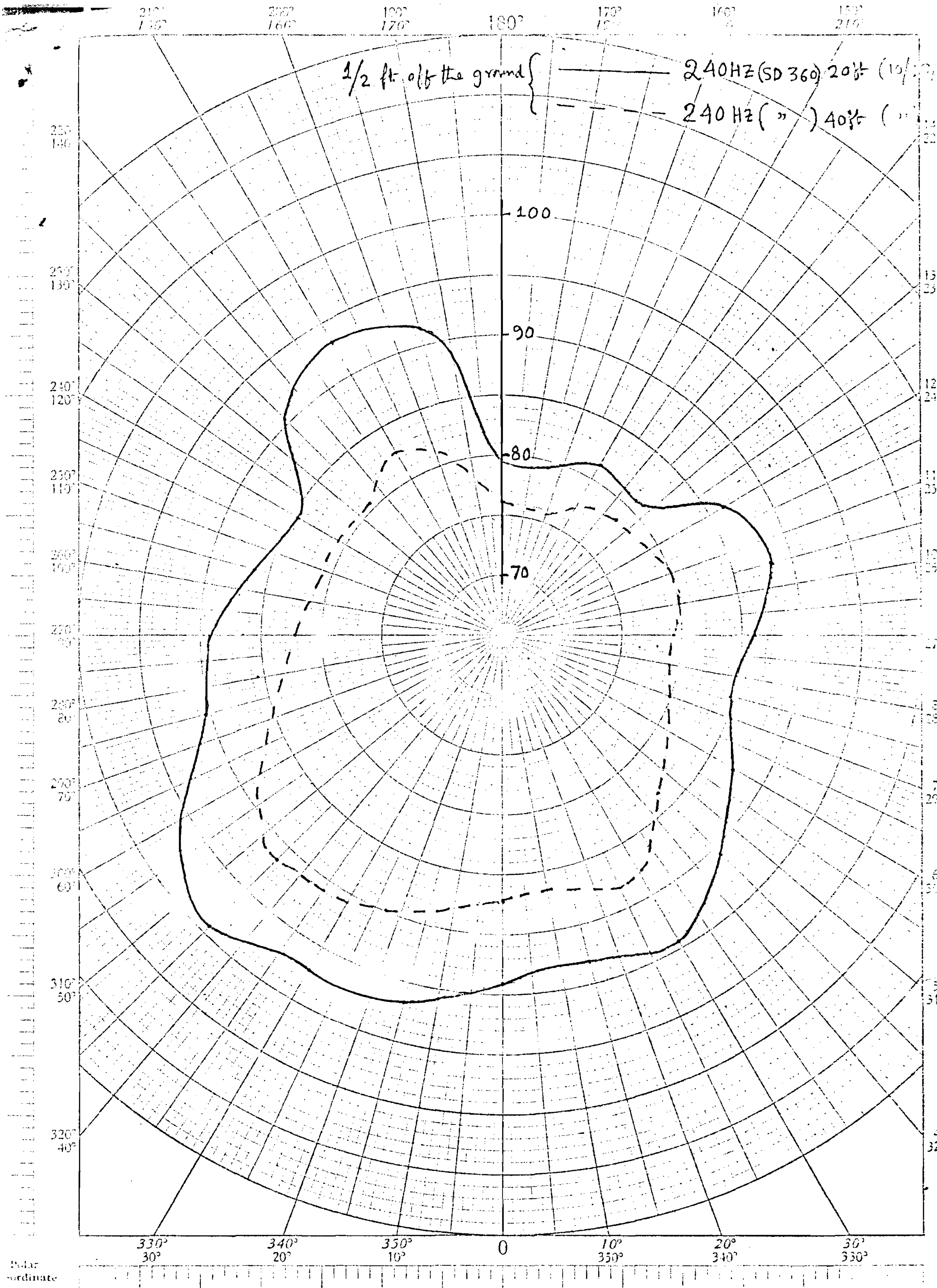
Data for measurement of SPL around the transformer tank at a 40 ft radial distance from the tank center.

The microphone placed at ½ ft off the ground

Frequency generator put on 240 H.Z
Test Cond. Reference ⇒ 110 dB = 0.
Frequency Range 0 to 1000 HZ.

Angular Postion (in degree)	SD Reading		Avg SD Reading	dB (110 − SD)
0	22.9	22.9	22.9	87.1
−45	18.8	18.6	18.7	91.3
−90	28.2	27.6	27.9	82.1
−135	30.3	29.0	29.65	80.35
−180	33.9		33.9	76.1
−225	36.6		36.6	73.4
−270	30.4	31.0	30.7	79.3
−315	26.2	26.6	26.4	83.6
−360	22.8	22.5	22.65	87.35

WITH ONE SPK'R ONLY ≈ 82% Magnitude


1/2 ft off the ground
240 HZ (SD 360) 20 ft
240 HZ (") 40 ft
100
90
80
70
180°
0
330° 30°
340° 20°
350° 10°
10° 350°
20° 340°
30° 330°
Polar
ordinate