URBAN PROPAGATION, WINNIPEG, 460 MHz:
A STUDY

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URBAN PROPAGATION
WINNIPEG
460 MHz

A study by David Dowse,
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under Summer Jobs Corps
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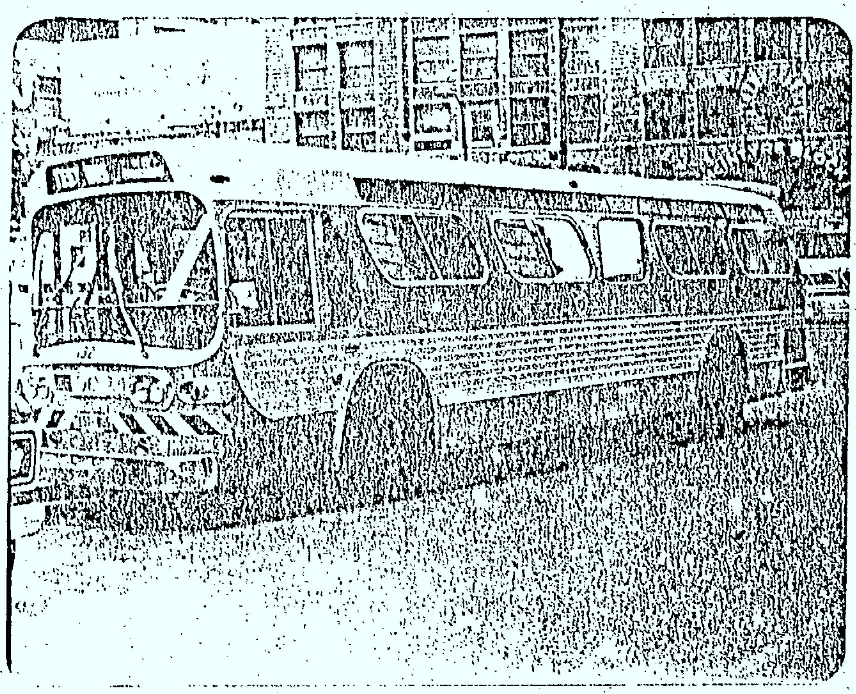
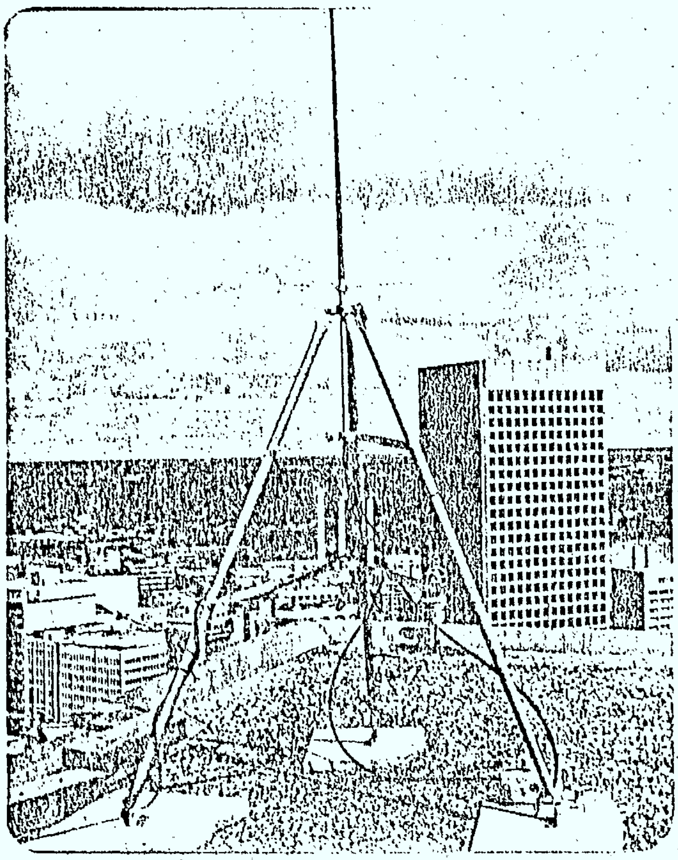
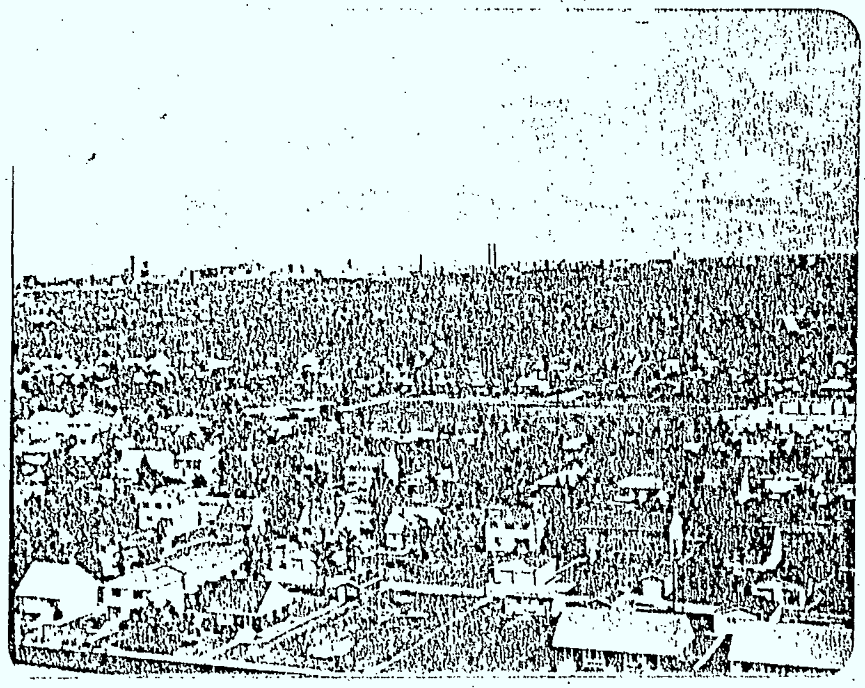


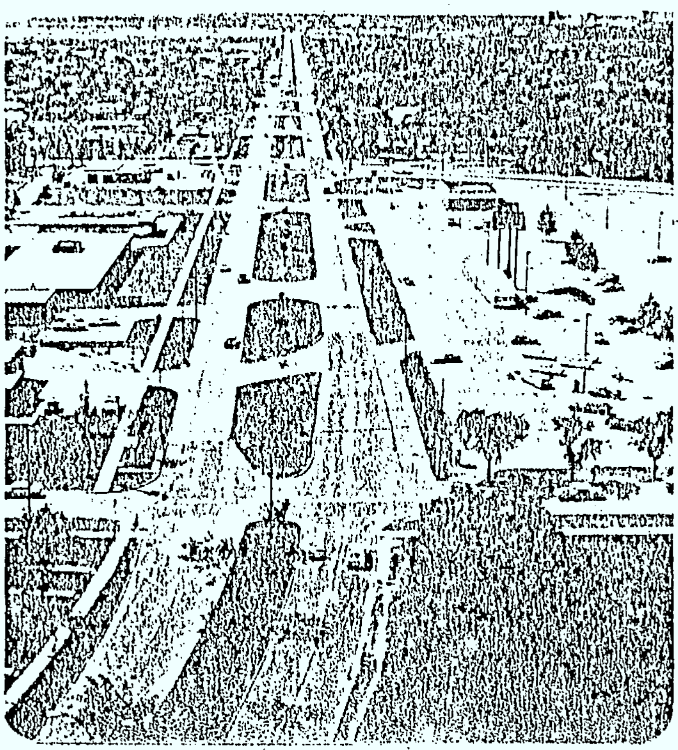
MOBILE TEST VEHICLE
USED IN PROJECT.



ANTENNA ON ROOF OF
NORTHSTAR REPEATER SITE.



VIEW FROM 1975
CORYDON TOWARDS
CENTER OF CITY.



VIEW FROM REPEATER
SITE AT 1975 CORYDON,
AWAY FROM CITY CENTER.

ABSTRACT

This report describes an urban UHF propagation study performed at 465 MHz in Winnipeg, Manitoba. A computerized data acquisition system mounted in a diesel bus enabled thorough measurement of the propagation environment. The results are presented as modifications to the Egli model, and should be useful for any large city with level terrain.

ACKNOWLEDGEMENTS

The authors are particularly grateful to:

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Ken Mount of the University of Manitoba applied statistics department, whose advice lent authority to our statistical analysis.

I. INTRODUCTION

A. Objective

The primary objective of this study was to provide a method of accurately forecasting UHF radio coverage in the City of Winnipeg. An accurate prediction of coverage based upon actual Winnipeg data would, it was hoped, enable reduction of licenced UHF transmitter powers while assuring adequate service to the users. Reduced power would significantly reduce both local intermod and fringe co-channel interference, thus conserving valuable spectrum.

B. Scope

The study was carried out in metropolitan Winnipeg, with the vast majority of measurements confined to built-up areas. Two transmitter sites were used, one 110 m high in the city centre and one 55 m high in the suburbs. All measurements were made at 465 MHz.

II. THE EXPERIMENT

A. Equipment

A sophisticated system was established to obtain the data used in this project. The system consisted of two fixed UHF repeaters, and a diesel bus which was equipped for mobile measurement and processing of UHF signal strength data.

Figure 1 (Section V) shows the system in block diagram form.

During the gathering of signal strength data, one of two remote repeaters was keyed by transmitting a signal from the bus on the particular repeater access frequency. This signal was repeated at 465 MHz and monitored by a receiver on the test bus. An analog output voltage was obtained from the test points of this receiver and found to be a monotonic function of signal strength at the RX input over the range -8 to 60 dBuV. This analog voltage was continuously fed into the analog to digital (A-D) converter of a PDP 11/10 minicomputer. The converter was set up so that a pulse from the bus speedometer triggered a digital input to the computer's CPU. Software was written to enable the CPU to interpret this digital input in terms of the signal strength of the RX input. When the bus was in motion, the speedometer pulse triggered the A-D board to output a digital value every 5 inches of bus travel.

The computer pre-processed the data in groups of samples. A pair of manual switches coupled to the CPU divided the stream of digital data input from the A-D board into discrete sets of samples. One button instructed the computer to begin a sample set, and the other to end it. Pre-processed data was output via a printer terminal also on the bus. More detail on the equipment is provided in Appendix 1. Details on calculation and measurement of the bus' receiving antenna factor are given in Appendix 4.

B. Procedure

Sites for the remote repeaters were carefully chosen to investigate propagation for transmitters situated both inside and outside the city centre. One repeater was set up on the Northstar Inn which is a 110 m high building located in the middle of the central business district. The other was placed on a 55 m high apartment building located at 1975 Corydon Avenue in a suburban area. Both of these buildings are the tallest in their immediate areas, and care was taken to ensure that the antennas were clear of obstacles on the roof of each building. These two factors ensured that the data gathered would be valid in all directions. The output power of each repeater was measured using an accurately calibrated power meter. Results are in Appendix 2.

The next step was to set up a system of routes over which the bus would travel and collect signal strength data. Routes were designed emanating radially from the TX site in all directions. This was the most efficient way to collect data relating signal strength and distance. Certain areas of the city were chosen for more detailed investigation through routes which included many of the streets in the area. Appendix 3 describes the routes used in the project.

At the beginning of each day that routes were to be run, a calibration check was performed on the mobile system. The system was found to have acceptable day to day stability. During normal data collection, the bus was in continuous motion along a route, with signal strength samples sent from the A-D board to the CPU every 5 inches of travel. Sample sets were begun and ended at intersections which could be precisely located on a map. In this way range (distance to the transmitter) could be determined for each sample set. Figure 2 (Section V) shows a typical sample set.

C. Data Format

Pre-processing of data consisted of determining the mean, standard deviation, and number of samples for each sample set, as well as sorting the samples taken into signal strength classes.

Figure 3 (Section V) shows a sample of pre-processed output.

Approximately 3500 sample sets were obtained from all parts of the city. This represents about 5.5×10^6 field strength readings or one reading every 5 inches for about 700 km.

III. DATA ANALYSIS

The experiment explained in the previous section enabled us to compile a very large and detailed data base for Winnipeg. This section will deal with the procedures used in obtaining models of the actual situation from this data.

A. Procedures

The data base obtained from the Northstar repeater was studied first, and in great detail.

The first analysis procedure was plotting the data on semi-log paper. With range on the log-scale X axis, and signal in dBuV on the y axis, any power relationship between signal and range would show up as a straight line on this type of graph. Each sample set was treated as a point, plotted with the mean signal in the set versus the range to the midpoint of the block.

From preliminary plots of data in this manner, it was judged that a straight line would fit the data reasonably well. Programs were devised for HP-25 and HP-97 programmable calculators to perform least squares linear regression on these data points.

At this initial stage in the analysis, we were very wary of making decisions about the data. For this reason, individual linear regressions were run on data obtained from each route. Each route was run 3 times and individual linear regressions were performed on these runs. Linear approximation was considered justified for the whole urban/suburban area (i.e. for ranges of 1 to 10 km from the Northstar).

The results of this analysis were encouraging:

- High coefficients of fit (r^2 = 0.8 or better) were obtained for these regressions. This confirmed the validity of the linear approximation.

- Regression results from different runs of each route were nearly identical. This meant that the data exhibited a clear and reproducible pattern.

- Regression results from routes run in many different directions from the transmitter were very similar. Thus data from routes run in all directions and through all areas of the city exhibited the same overall pattern. It was judged that data obtained from all these separate routes could be considered representative of the same general propagation effects.

These results, especially the last, indicated the possibility and validity of a general model of the propagation conditions based on this data. A plot of the average signal strengths from different runs of each route vs range gives a good idea of the overall data picture. See Figure 4 (Section V).

Analysis was done combining data from all routes into the same model, using some more sophisticated techniques. One characteristic of the sample sets making up the data base is that they do not represent equal numbers of samples. A technique was devised whereby each point in a regression analysis was weighted by the number of signal strength readings it represented. In this way, as long as the sample sets were kept to a reasonable size, weighted regression compensated nicely for variations in block length.

Weighted regression analysis produced a line of best fit for the data gathered from Northstar repeater. 1 km was set as a lower range limit because investigation of the antenna pattern indicated that repeater antenna lobing would result in a distorted picture below this range. The upper range limit was set at 10 km because this was the maximum extent of the built-up area.

It will be noted from Figure 4 (Section V) that there is a dispersion of signal strength data at any particular range. Broadly speaking, the data is centered about a line but dispersed around it. We sought to investigate and model this dispersion.

A program was written for the HP-97 that accepted the linear regression results and the data points from Figure 4 and produced histograms describing the deviation of the points from the line. An example of the results is shown in Figure 5 (Section V).

The histogram seemed to indicate a log-normal distribution[1], as found by Revdink and others.

Next, a method was devised to combine the individual distribution characteristics of a number of sample sets into a set of overall distribution characteristics. An HP-97 program was written to do this data combination, accepting individual mean, standard deviation, and number of samples and returning an overall mean and standard deviation. (See Appendix 6). Data was combined in this way in a series of ninety 0.1 km bins between 1 and 10 km. The results are shown graphically in Figure 6 (Section V). It was noted that the standard deviation of the data was roughly constant over the entire 1 to 10 km range. This fact combined with the regression results and the log-normal distribution gave a good description of the actual situation.

1. i.e. a normal distribution where the x-axis is a logaritimic scale.

In analyzing the data from 1975 Corydon, use was made of the results of the previous Northstar analysis. Grouped analysis was started immediately with the plotting of data in Figure 7. On the basis of this graph and observation of local terrain conditions, certain data was put into a separate rural model.

Weighted linear regression was done on both urban/suburbran and rural data, resulting in separate models for each. The built-up area extends to 17 km range for 1975 Corydon, as compared with 10 km for the Northstar. Data dispersion for this repeater was similar to that of the Northstar.

B. Results

Weighted linear regression results are summarized in Figure 8 (Section V). Note that the slopes are very consistent for all the models. Comparison of rural and urban/suburban results for 1975 Corydon reveals that while the slopes are very similar, reception in rural areas is about 11 dB higher than in built up areas.

The urban/suburban results from 1975 Corydon are based on data gathered up to a 17 km range. For this reason it seems justified to assume that the slope of -28-1 dB per decade seen in results from both transmitters would apply for built-up areas to at least a 20 km range.

The consistent standard deviation of the data dispersion has been noted previously. The mean of the standard deviations shown in Figure 6 is 6.6 dB. It is thus reasonable to describe the urban/ suburban data by a band centered about the weighted linear regression line. Using the log-normal dispersion approximation, it is possible to predict that about 2/3 of the data will fall within a band 1 standard deviation on either side of the linear regression line. (See Figure 9 Section V). Unfortunately there is not adequate data to present the rural data this way.

Significantly, the data shows a homogeneous propagation environment, without the urban/suburban distinction which has been found in other cities. For example (see Appendix 8), propagation loss from the suburban repeater to the core area is essentially identical to that of the overall model. The built-up area of Winnipeg can thus be considered a uniform reception environment.

Another separate result which bears mentioning is the amplitude distribution observed within individual sample sets. A Rayleigh distribution (resembling a log-normal distribution skewed towards the low side) has a theoretical basis and has been observed in other studies. This type of distribution was observed in almost all sample sets obtained during the survey. A typical distribution is shown in Figure 10 (Section V). The standard deviations of local distributions obtained in this study range from 0 to 10 dB but most were around 4 dB.

IV. CONCLUSIONS

A. The Final Model

The linear regression lines representing the entire urban/suburban data base are:

Northstar TX:

$$E_{in}(dBuV/_{50\Omega}) = 50.7 - 27.2 \log d \qquad \text{(d in Km)}$$

1975 Corydon TX:

$$E_{in}(dBuV/_{50\Omega}) = 50.9 - 29.4 \log d \qquad \text{(d in Km)}$$

From Appendix 10, the corresponding Egli predictions are:

Northstar TX:

$$E_{in}(dBuV/_{50\Omega}) = 45.9 - 40 \log d \qquad \text{(d in Km)}$$

1975 Corydon TX:

$$E_{in}(dBuV/_{50\Omega}) = 41.2 - 40 \log d \qquad \text{(d in Km)}$$

Thus the Northstar signal measured at 1 km is (50.7 - 45.9) = 4.8 db higher than Egli predicts, while the 1975 Corydon signal is (50.9 - 41.2) = 9.7 dB higher at 1 km. At d = 10 km, the differences become 17.6 dB and 20.3 dB respectively. A conservative model for Winnipeg could thus have about 5 dB less loss at 1 km than Egli predicts, and a slope of about 30 dB per decade of distance.

Applying these modifications to the Egli loss equations given by Palmer (Review of Propagation in the 470-890 MHz Band, CRC Report 1288, Department of Communications, Ottawa. (1976)) yields the following expression for L_{50}, the median loss between two half-wave dipoles in the Winnipeg area:

$$L_{50}(\text{dB}) = 95 + 20 \log f + 30 \log d - 20 \log h_t - 10 \log h_r$$

for: f in MHz

d in km

h in m, and $h_r \leq 9.1$ m(30')

This expression for loss assumes Egli's frequency dependence and height gain factors are accurate for the Winnipeg environment, as the experiment did not allow verification of these factors. A very simple first-order check of TX height gain showed 4 dB higher levels from the Northstar (Egli predicts 6 dB), but the overall data base showed only about 1 dB difference at 1 km, increasing to 3.3 dB at 10 km. See Appendix 9.

A very significant part of this loss model is the standard deviation of the overall sample population. Egli's paper suggests standard deviations on the order of 10 or 11 dB, but our data yielded 6.6 dB as an average from 1-10 km. Since the distribution of samples is approximately log normal, this reduction of standard deviation will greatly reduce the power increases necessary to upgrade coverage to the 90% or 99% reliability levels. The discrepancy between Egli's figure and ours is largely due to the fact that his figures were drawn from a variety of terrain types.

Data from rural areas surveyed indicated a signal level about 11 dB higher than that for built-up areas, but with a similar distance dependence.

B. Area of Applicability

The survey results indicate that the model should hold well for built-up areas (urban or suburban) to at least a 20 km range. The level terrain of Winnipeg is similar to that of many cities on the great plains, thus allowing wide application of this loss equation.

The results also reveal no significant loss variations between radial routes and tangential ones, a slightly unexpected discovery. Multipath effects would explain this in the core area, but in residential suburbs it is possible that this uniformity was partly due to the unusual elevation of the test bus antenna (3 m rather than 1 m for a normal automobile).

V. FIGURES 1 TO 10

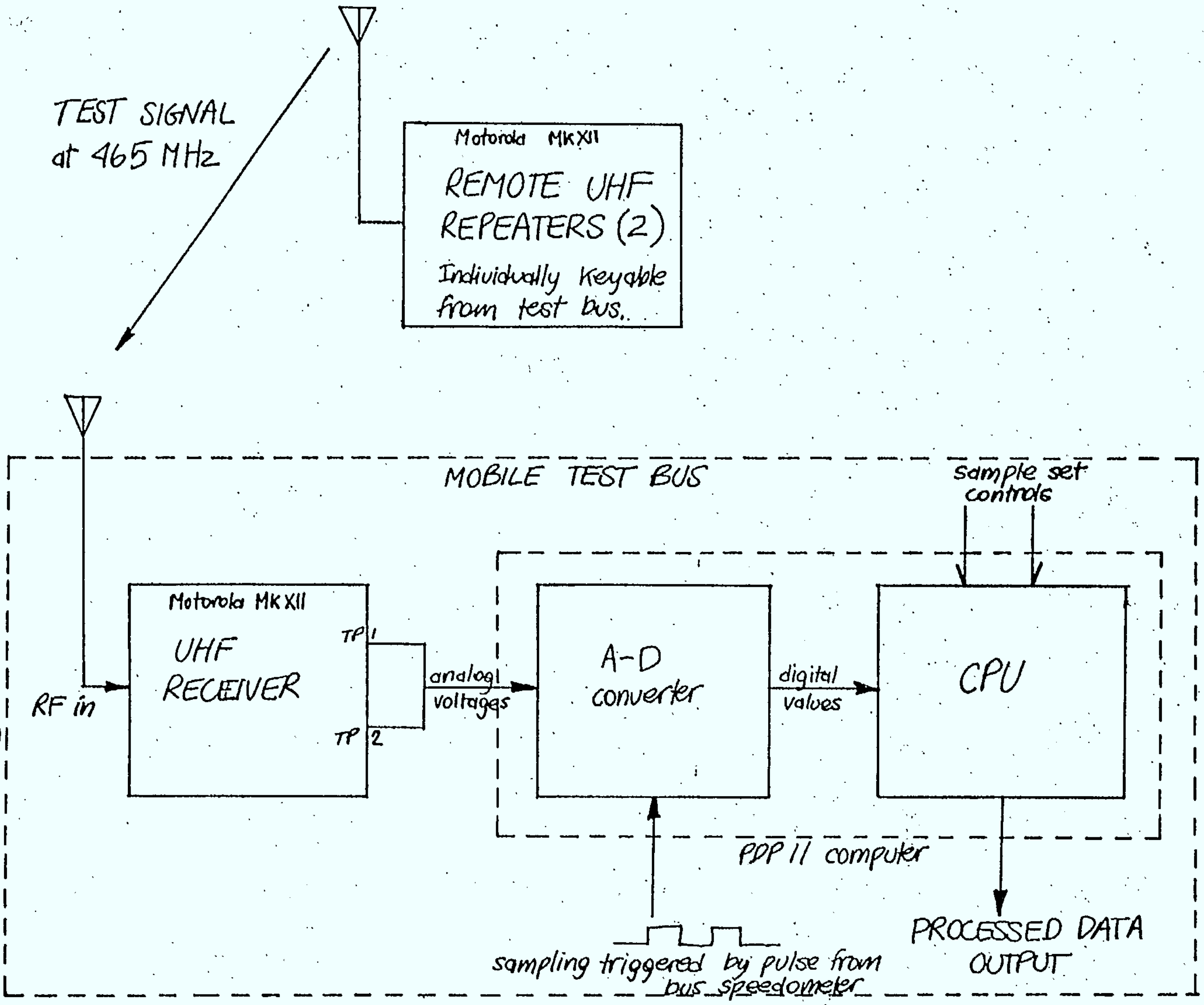


FIG 1 Block diagram of equipment used.

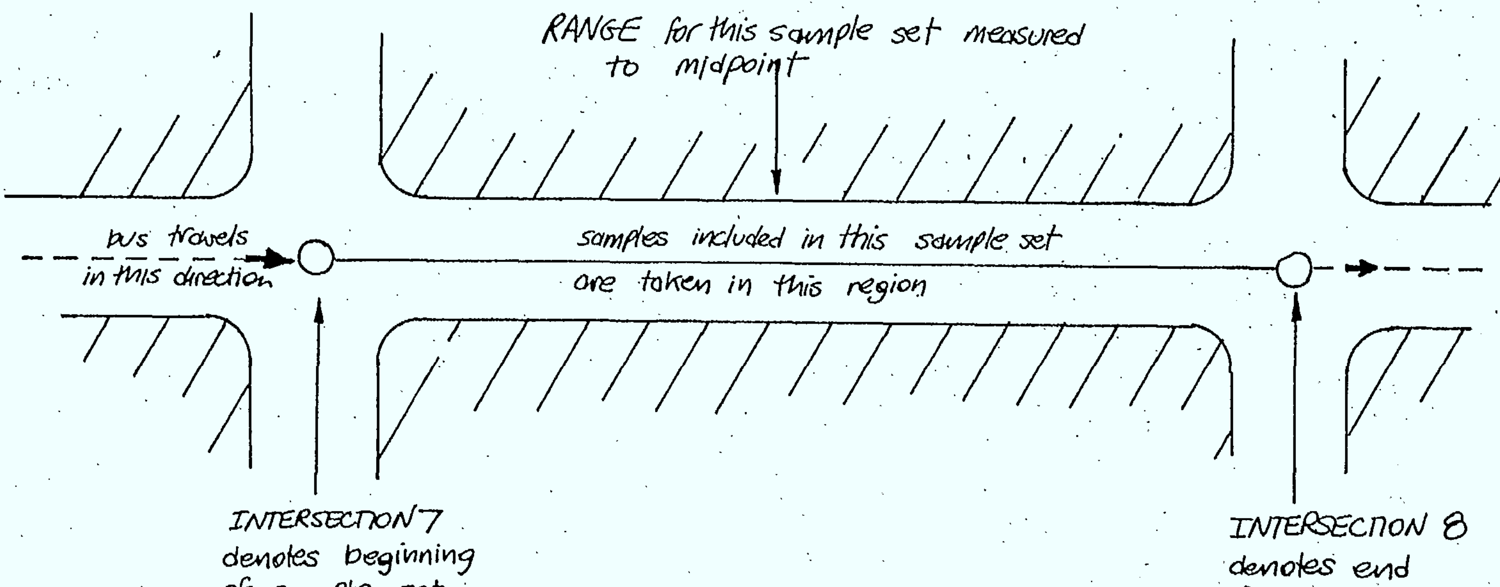


FIG 2 A typical sample set

Intersection numbers denoting beginning and end of sample set.

The other numbers are percent readings in 4 dB signal classes between −8 and 60 dBµV/RX.

eg. 3.6 % of readings were between 16 and 20 dBµV/RX

```
INTERSECTION     7 -
   0.0%     0.0%     0.0%     0.3%     0.8%     1.8%     3.6%     9.4%    22.2%
  40.6%    21.3%     0.1%     0.0%     0.0%     0.0%     0.0%     0.0%     0.0%
           28.3      4.9      2267
INTERSECTION     8 -
```

number of samples in this sample set.

% samples above 60dBµV/RX

standard deviation dB

mean signal in sample set dBµV/RX

FIG 3 Typical output.

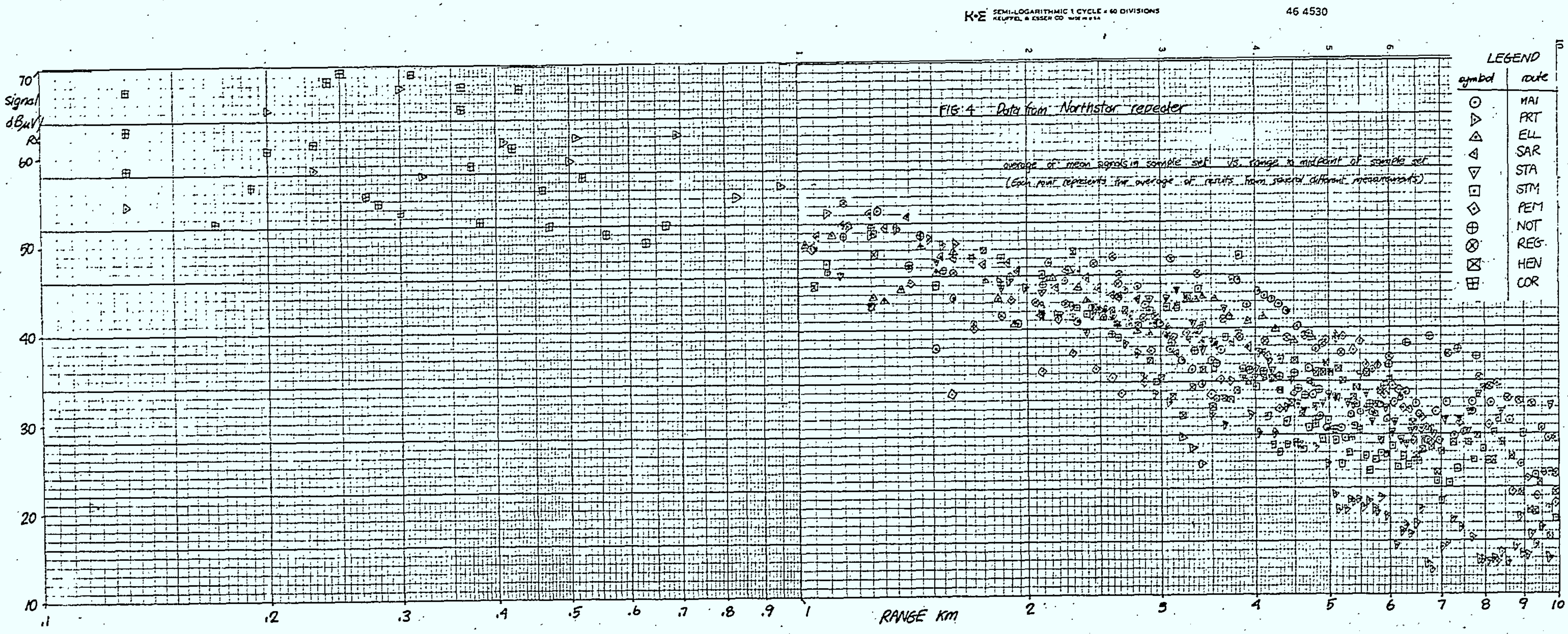


FIG 4 Data from Northstar repeater

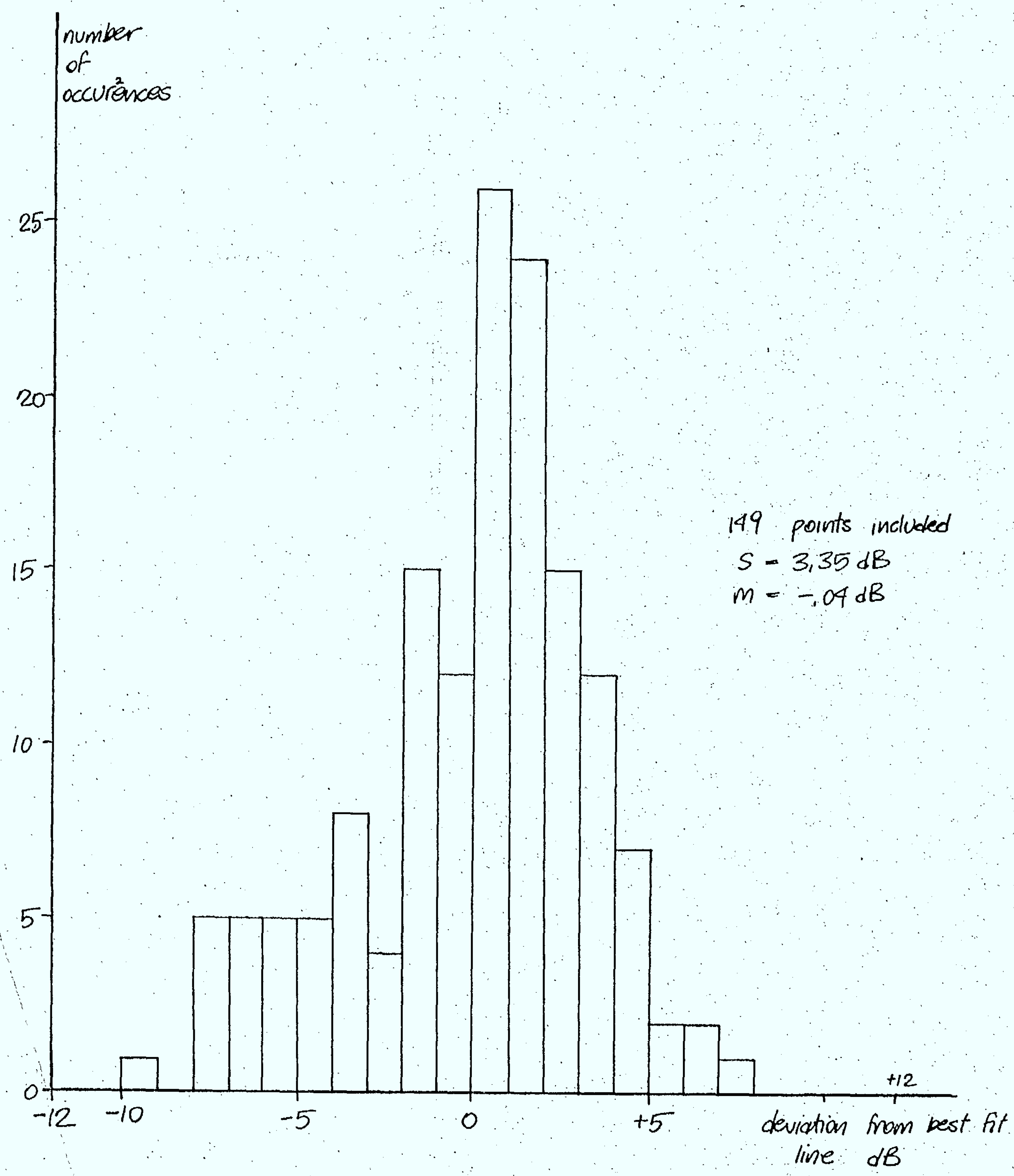


FIG 5. Histogram of deviation from best fit line for points between 1 and 3 km range on FIG 4.

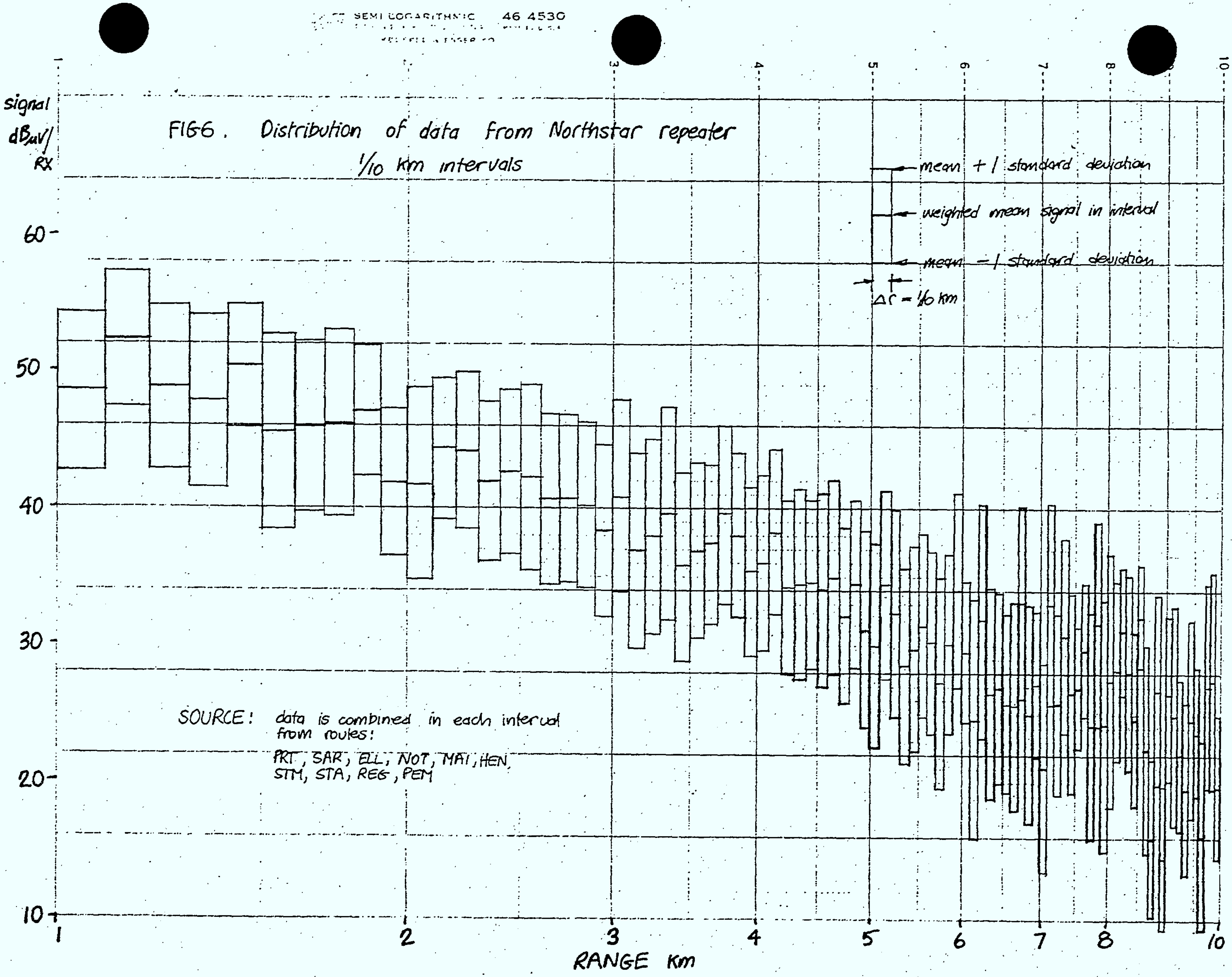
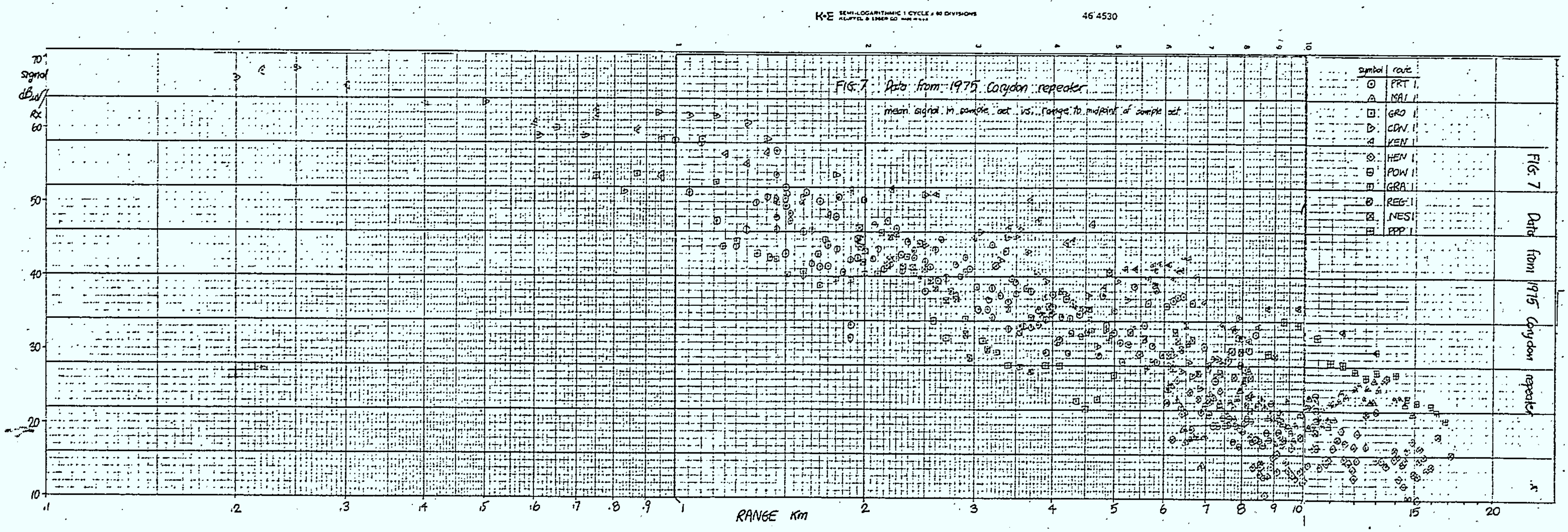


FIG. 6 Distribution of data, 1/10 km intervals



K•E SEMI-LOGARITHMIC 1 CYCLE x 60 DIVISIONS
46 4530
FIG. 7 Data from 1975 Corydon repeater
mean signal in sample set vs. range to midpoint of sample set
signal dB$_{\mu V}$ Rx
70
60
50
40
30
20
10
.1
.2
.3
.4
.5
.6
.7
.8
.9
1
2
3
4
5
6
7
8
9
10
15
20
RANGE Km
symbol | route
PRT I
MAI I
GRO I
CDN I
KEN I
HEN I
POW I
GRA I
REG I
NES I
PPP I
FIG. 7 Data from 1975 Corydon repeater

The results apply for the y-axis in dBuV/RX on a linear scale and the x-axis in km on a log scale.

Y_0 denotes the y intercept at 1km in dBuV/RX

m denotes the slope in dB/decade

r^2 is the coefficient of fit.

I Results for data from Northstar repeater

m = -27.22 dB/dec
Y_0 = 50.68 dBuV/RX
r^2 = .58

sample sets – 1884.

samples represented – 3073065.

II Results for data from 1975 Corydon repeater

A. urban/suburban

m = -29.43 dB/dec
Y_0 = 50.87 dBuV/RX
r^2 = .78

sample sets – 1204.

samples represented 2098869.

B. rural

m = -31.53 dB/dec
Y_0 – 61.79 dBuV/RX
r^2 .92

sample sets – 135.

samples represented 412115.

FIG 8 Summary of weighted linear regression results

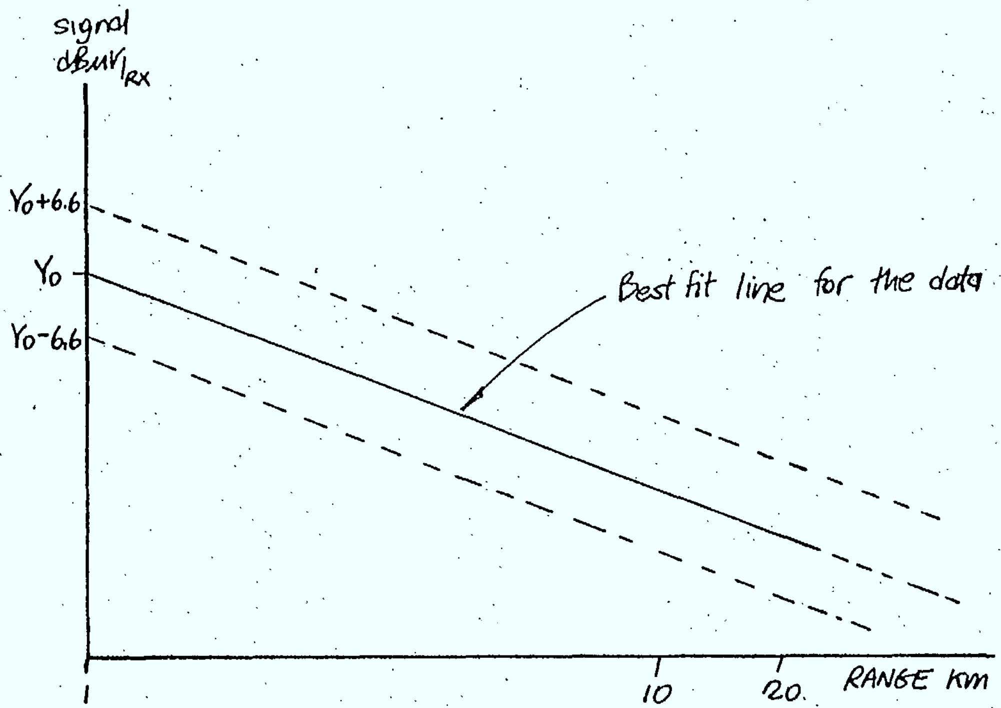


FIG 9 Band enclosing ≈ 2/3 of data

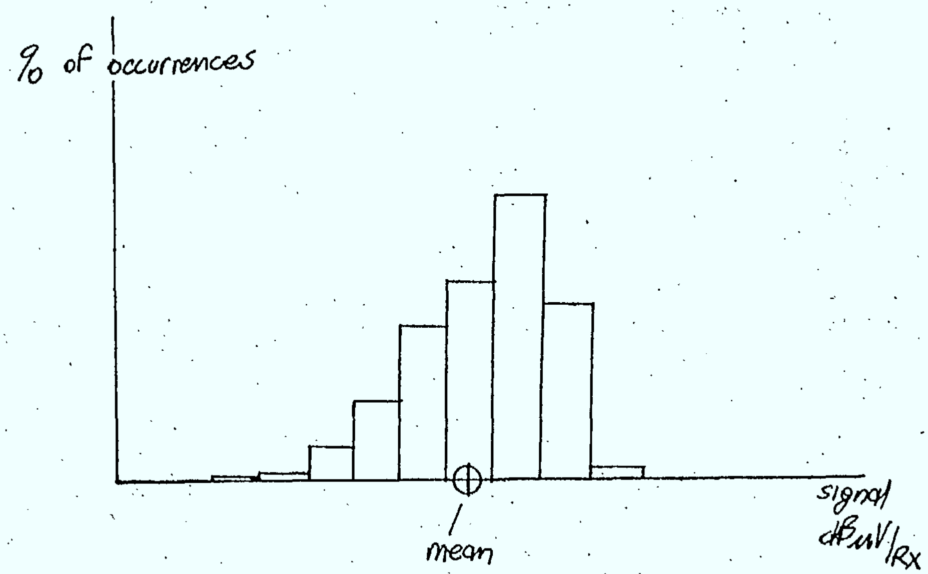


FIG 10 A typical local signal strength distribution

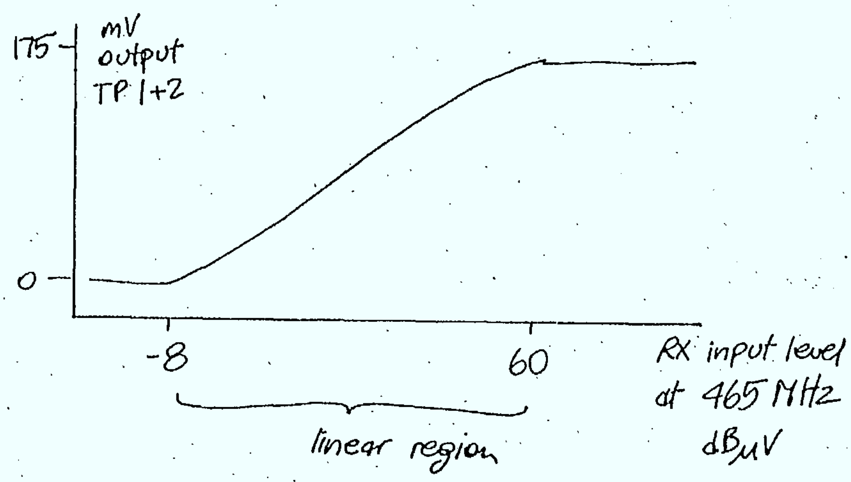
APPENDIX 1

EQUIPMENT TYPES

Test vehicle	- GMC Diesel Passenger Bus
Repeaters	- Motorola MK XII UHF transceivers in repeater configuration
Repeater antennas	- Sinclair 329A collinear for 453.0 MHz (6.1 dBd gain)
Test Receiver	- Motorola MK XII UHF transceiver
Test receiver antenna	- $\lambda/4$ whip mounted on roof of test bus
Computer	- Digital Equipment PDP 11/10 computer with analog interface.

SET-UP and CALIBRATION

Combining the outputs from test points 1 and 2 on the test receiver produced an analog voltage related to signal strength at the RX input. The precise nature of this output was investigated using a voltmeter and an accurate HP 8640B signal generator. The results were as follows:



Exact digital equivalents for a number of points in the linear region were obtained and programmed into the computer as signal class limits for the sorting routine.

APPENDIX 2

REPEATER POWER MEASUREMENTS

Two power measurements were made at each TX site, one before and one after the measurement program. Results are tabled below (in Watts):

NORTHSTAR TX

	At TX Fwd.	At TX Rev.	At Antenna Fwd.	At Antenna Rev.	ERP[1]	EIRP[2]
July 5/77	13.0	1.2	6.7	0.4[3]	25.7	42.1
Aug. 17/77	15.5	1.5	5.8	0.4	22.0	36.1
NORTHSTAR AVERAGE:					23.9	39.1

1975 CORYDON TX

	At TX Fwd.	At TX Rev.	At Antenna Fwd.	At Antenna Rev.	ERP[1]	EIRP[2]
July 5/77	17.4	2.4	8.1	1.5	26.9	44.1
Aug. 17/77	21.3	2.2	10.3	1.0	37.9	62.1
1975 CORYDON AVERAGE:					32.6	53.1

Overall accuracy of above figures is ± 0.3 dB.

NOTES:

1. Reference to half-wave dipole. Includes 6.1 dB TX antenna gain with respect to dipols.

2. Includes 2.15 dB gain to reference to isotropic antenna.

3. Estimated from August 17 data.

APPENDIX 3

Description of the location of routes used in this project.

I. RADIALS - have generally radial orientation wrt TX site.

A. Used for both 1975 Corydon and Northstar.

NAME	LOCATION
PRT	Portage Avenue between downtown and perimeter
NES	Ness Avenue
POW	Powers Street
MAI	Main Street between downtown and perimeter
HEN	Henderson Highway between downtown and perimeter
REG	Regent and other streets between downtown and perimeter

B. Used for Northstar only

NOT	Notre Dame
SAR	Sargen
ELL	Ellice
STA	St. Annes Road
STM	St. Mary's Road — between downtown and perimeter
PEM	Pembina Highway

C. Used for 1975 Corydon only

KEN	Kenaston Boulevard
CDN	Corydon/Roblin
GRA	Grant
GRO	Grosvenor

II. AREAS - To obtain detailed data from specific areas.

STJ	St. James
S-E	Streets between Sargent and Ellice
N-E	North End
TRA	Transcona
R-H	River Heights
UNV	University of Manitoba Campus
COR	Central Business District
COS	Central Business District
COT	Central Business District

APPENDIX 4

BUS ANTENNA FACTOR

A. Calculated

Assume that a quarter-wave whip antenna above a conducting plane is internally matched to 50 ohm feedline consisting of 20 feet of RG-58 to 50 receiver input.

Antenna matching loss	0.25 dB
Line loss @ 465 MHz (14 dB per 100 ft.)	2.8 dB
System loss	3.05 dB

Actual length of whip = h = 5 1/8" = 13.0 cm.

Effective height = 8.3 cm = 21.6 dB below 1m.

At match, radiation resistance of antenna forms a voltage divider with RX input impedance, causing 3 dB additional loss.

Thus overall system transducer loss (= ant. factor, AF) is

$$AF = 3.05 + 21.6 + 3 = 27.65 \text{ dB}$$

B. Measured

The antenna factor was verified experimentally using a Singer NM37/57 field strength meter with its calibrated log spiral antenna. The signal input to the NM37/57 by the bus antenna was compared (for 4 bus orientations) with the actual field strength measured with the log spiral antenna in the same position. The difference between these figures gave the antenna factor plus cable loss for the bus whip antenna.

The results were:

Field intensity measured with log spiral antenna 73.2 dB V/m

Bus antenna output:

- left side to TX	50.9 dB V
- front to TX	50.4
- right side to TX	51.2
- back to TX	48.0
Average:	50.1 dB V

Bus antenna factor and cable loss = 73.2-50.1 = 23.1 dB

This is (27.65 - 23.1) = 4.55 dB lower than calculated, a reasonable agreement in light of the vagaries of the mobile antenna environment. Probably part of the difference is due to line losses in the bus system being lower than calculated.

Overall accuracy of the measured antenna factor and cable loss is about ± 1 dB, as the NM37/57 absolute error does not affect the differential results.

The 3 dB lower sensitivity of the antenna for signals from behind the bus was also noticed in runs made in rural areas where local scattering was minimal.

APPENDIX 5

WEIGHTED LINEAR REGRESSION

Theory: The standard linear regression procedures were modified to handle data where each data point might represent a different number of samples.

If (x_i, y_i) occurs n_i times, it must be absorbed into the regression analysis n_i times.

i.e. $\sum_i x_i y_i$ becomes $\sum_i n_i x_i y_i$ etc.

using this procedure;

(slope) $$m = \frac{\sum n_i x_i y_i - \frac{\sum n_i x_i \sum n_i y_i}{\sum n_i}}{\sum n_i x_i^2 - \frac{(\sum n_i x_i)^2}{\sum n_i}}$$

(Intercept) $Y_0 = \bar{y} - \bar{x} m$

(fit coefficient) r^2 is developed in a similar way

The program accepts x_i, y_i and n_i and returns m, Y_0 and r^2.

Program Listing.

```
INITIALIZE          001  *LBLA
                    002  CLRG
                    003  CLX
                    004  PRTX
                    005  SPC
                    006  SPC
                    007  RTN
option  Log         008  *LBLD
        X scale     009  SF1
                    010  RTN
        Linear      011  *LBLd
        x scale     012  CF1
                    013  RTN
PROCESS             014  *LBLE
DATA                015  STOA
                    016  (ST+0 -Σni)
develops            017  R↓
the neccessary      018  STOB
summations.         019  R↓
                    020  F1?
accepts             021  LOG
xi, yi, ni          022  STOC
as often            023  RCLA
as required.        024  x
                    025  (ST+1 Σnixi)
                    026  RCLB
                    027  RCLA
                    028  x
                    029  (ST+2 -Σniyi)
                    030  RCLA
                    031  RCLB
                    032  RCLC
                    033  x
                    034  x
                    035  (ST+3 Σnixiyi)
                    036  RCLA
                    037  RCLC
                    038  X²
                    039  x
                    040  (ST+4 Σnixi²)
                    041  RCLB
                    042  X²
                    043  RCLA
                    044  x
                    045  (ST+5 Σniyi²)
                    046  ISZI
                    047  RCLI
                    048  RTN
LIST                049  *LBLB
RESULTS             050  RCL3
                    051  RCL1
calculates          052  RCL2
and                 053  x
prints              054  RCL0
V0, m, r²           055  ÷
when                056  -
all data            057  STO9
has been            058  RCL4
input.              059  RCL1
                    060  X²
                    061  RCL0
                    062  ÷
                    063  -
                    064  STO8
                    065  ÷
                    066  PRTX(m)
                    067  RCL1
                    068  RCL0
                    069  ÷
                    070  RCL2
                    071  RCL0
                    072  ÷
                    073  R↓
                    074  x
                    075  R↑
                    076  X⇄Y
                    077  -
                    078  PRTX(Y0)
                    079  RCL5
                    080  RCL2
                    081  X²
                    082  RCL0
                    083  ÷
                    084  -
                    085  RCL8
                    086  x
                    087  RCL9
                    088  X²
                    089  X⇄Y
                    090  ÷
                    091  PRTX(r²)
                    092  CLX
                    093  RTN
ERROR               094  *LBLe
RECOVER             095  RCLA
                    096  ST-0
removes             097  RCLC
the effect          098  RCLA
of processing       099  x
an incorrect        100  ST-1
data point          101  RCLB
                    102  RCLA
                    103  x
                    104  ST-2
                    105  RCLA
                    106  RCLB
                    107  RCLC
                    108  x
                    109  x
                    110  ST-3
                    111  RCLA
                    112  RCLC
                    113  X²
                    114  x
                    115  ST-4
                    116  RCLB
                    117  X²
                    118  RCLA
                    119  x
                    120  ST-5
                    121  DSZI
                    122  RCLI
                    123  RTN
                    124  R/S
```

APPENDIX 6

COMBINING DISTRIBUTIONS

Summary: An HP-97 program was written to accept the characteristics of a number of individual distributions ($\bar{X}_i$, S_i , n_i) and return the characteristics of the distribution that would be obtained if these individual distributions were combined ($\bar{X}_o$, S_o , n_o).

Theory: (i denotes individual, o denotes overall)

For each individual distribution, the program calculates

$$(\Sigma X^2)_i = (n_i - 1) S_i^2 + n_i (\bar{X}_i)^2$$

and develops the following summations:

$$\sum_i (\Sigma X^2)_i \quad , \quad \sum_i n_i \quad , \quad \sum_i n_i \bar{X}_i$$

Then the overall characteristics are given by:

$$\bar{X}_o = \frac{\sum_i n_i \bar{X}_i}{\sum_i n_i} \quad \text{(weighted mean)}$$

$$S_o^2 = \frac{\sum_i (\Sigma X^2)_i - \left(\sum_i n_i \bar{X}_i\right)^2 / \sum_i n_i}{\left(\sum_i n_i\right) - 1}$$

PROGRAM LISTING

INITIALIZE

initializes register contents

```
001  *LBLA
002  CLRG
003  P⇄S
004  CLRG
005     8
006     8
007     8
008     8
009     8
010     8
011     8
012     8
013     8
014     8
015   SPC
016  PRTX
017   SPC
018   CLX
019  DSP2
020   RTN
```

ACCEPT INDIVIDUAL CHARACTERISTICS

T, Z: $\bar{X}_i$ · Y: S_i · X: n_i

accepts $\overline{X}_i$, S_i, n_i and develops neccessary summations.

```
021  *LBLE
022  STO0
023    R↓
024  STO1
025  [illegible]
026  STO2
027    R↑
028    Σ+
029  STOI
030  RCL2
031  RCL1
032  RCL0
033  ENT↑
034    R↑
035    X²
036     x
037  ENT↑
038    R↓
039   CLX
040     1
041     -
042   X⇄Y
043    X²
044     x
045     +
046  STO3
047   P⇄S
048  ST+3
049  RCLI
050  DSP2
051   P⇄S
052   RTN
```

error correction routine

```
053  *LBLe
054  RCL3
055   P⇄S
056  ST-3
057   P⇄S
058  RCL2
059  RCL0
060    Σ-
061  DSP2
062   RTN
```

LIST OVERALL CHARACTERISTICS

calculates and prints overall characteristics

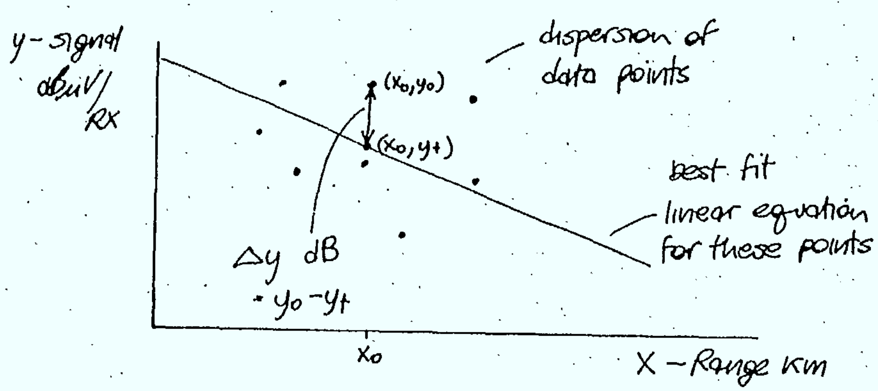
```
     *LBLB
      P⇄S
     RCL9
 ...
066  DSP0
067  PRTX
068  RCL4
069  PRTX
070   SPC
071  RCL8
072  RCL4
073     ÷
074  DSP2
075  PRTX
076  RCL4
077    √X
078     ÷
079  PRTX
080   SPC
081  RCL3
082  RCL8
083    X²
084  RCL4
085     ÷
086     -
087  RCL4
088     1
089     -
090     ÷
091    √X
092  PRTX
093  RCL4
094     2
095     x
096    √X
097     ÷
098  PRTX
099   P⇄S
100   CLX
101   RTN
102   R/S
```

APPENDIX 7

Part A

HP-97 program for computing data dispersion histograms.

A. Summary: The program accepts the equation of the line about which the data is dispersed, and the coordinates of the data points. For each data point, the program computes the y coordinate from the equation of the line, and then subtracts it from the coordinate of the data point. Each Δy obtained in this way is sorted into a set of 24 1 dB wide bins between -12 and 12 dB deviation.



The program outputs a list of Δy's calculated and the results of the sorting process. It also calculates mean and standard deviation of Δy's.

The program outputs a list of Δy's calculated and the results of the sorting process. It also calculates mean and standard deviation of Δy's.

APPENDIX 7
Part B

B PROGRAM LISTING

	step	instruction
INITIALIZE	001	*LBLA
	002	CLRG
	003	P⇄S
	004	CLRG
	005	P⇄S
places	006	CF1
correct	007	1
contents	008	2
in memory	009	CHS
to begin	010	STOC
program.	011	CHS
	012	STOD
	013	X⇄Y
	014	2
	015	4
	016	STOE
	017	1
	018	STOA
	019	FIX
	020	DSP0
	021	RTN
accepts	022	*LBLB
equation	023	STO0
of	024	R↓
line of	025	STO1
best fit.	026	P⇄S
	027	GSB6
	028	RTN
	029	*LBLe
	030	RCL0
error	031	0
correction	032	STOI
routine	033	X⇄Y
	034	Σ-
	035	SPC
	036	SF1
	037	GSBc
	038	CF1
	039	RTN
SORT ΔY's	040	*LBLE
accepts	041	X⇄Y
x-y coordinates	042	LOG – x-scale is a log scale
of data	043	P⇄S
points.	044	RCL0
	045	x
	046	RCL1
	047	+
	048	-
	049	P⇄S
calculates	050	STO0
and	051	3
	052	STOI
	053	R↓
	054	DSP2
prints Δy	055	PRTX
	056	RCLC
	057	X>Y?

	step	instruction
	058	GTO0
	059	R↓
	060	RCLD
	061	X⇄Y
	062	X>Y?
	063	GTO0
	064	0
	065	X⇄Y
	066	Σ+
	067	*LBLc
	068	STO9
sorts	069	RCL0
numbers	070	RCLD
(Δy)	071	X⇄Y
into	072	X=Y?
bins	073	GSB2
	074	RCLC
	075	-
	076	RCLA
	077	1/X
	078	x
	079	INT
	080	1
	081	X⇄Y
	082	+
	083	LSTX
	084	3
	085	÷
	086	INT
	087	1
	088	+
	089	STOI
	090	1
	091	-
	092	3
	093	x
	094	-
	095	GTOi
	096	*LBL3
	097	RCL9
	098	DSP0
	099	DSP2
	100	CF1
	101	R/S
	102	RTN
	103	*LBL1
	104	GSBd
	105	F1?
	106	CHS
	107	ST+i
	108	GTO9
	109	*LBLd
	110	3
	111	CHS
	112	x
	113	10^x
	114	RTN

	step	instruction
LIST	115	*LBLC
HISTOGRAM	116	GSB6
	117	0
	118	STOI
	119	RCLC
	120	STOB
	121	*LBL5
	122	ISZI
	123	2
	124	STO9
	125	GSBa
calculates	126	RCLi
and	127	EEX
outputs	128	3
number	129	x
of Δy's	130	INT
occuring	131	DSP0
in each	132	PRTX
bin	133	SPC
	134	DSP2
	135	1
	136	STO9
	137	GSBa
	138	RCLi
	139	EEX
	140	3
	141	x
	142	FRC
	143	EEX
	144	3
	145	x
	146	INT
	147	DSP0
	148	PRTX
	149	SPC
	150	DSP2
	151	0
	152	STO9
	153	GSBa
	154	RCLi
	155	EEX
	156	6
	157	x
	158	FRC
	159	EEX
	160	3
	161	x
	162	INT
	163	DSP0
	164	PRTX
	165	SPC
	166	DSP2
	167	RCLI
	168	8
	169	X>Y?
	170	GTO5
	171	RTN

	step	instruction
	172	*LBLa
	173	RCLB
	174	PRTX
	175	RCLC
	176	RCLA
	177	RCLI
	178	3
	179	x
	180	RCL9
	181	-
	182	x
	183	+
	184	PRTX
	185	STO6
	186	RTN
	187	*LBLD
calculates	188	DSP2
and	189	GSB6
prints	190	P⇄S
mean	191	RCL9
and	192	P⇄S
stand.	193	PRTX
dev.	194	x̄ – mean
of Δy's	195	PRTX
	196	S – stand. dev.
	197	PRTX
	198	GSB6
	199	RTN
	200	*LBL2
	201	RCLA
internal	202	2
routines	203	÷
	204	-
	205	RTN
	206	*LBL6
	207	SPC
	208	SPC
	209	8
	210	8
	211	8
	212	8
	213	8
	214	8
	215	8
	216	8
	217	8
	218	8
	219	PRTX
	220	SPC
	221	RTN
	222	R/S

APPENDIX 8

PROPAGATION TO CITY CENTER

Reception in center of city from repeater situated outside the center.

- mean of data gathered in center of city

(ROUTE CORI) $\bar{X}$ - 27.43 $dBuV/_{RX}$

- result predicted by model

(RANGE = 5.5 km) $X_p = 50.87 - 29.43 \log (5.5)$

$X_p = 29.08$

$X_p - \bar{X} = 1.65$ dB

APPENDIX 9

HEIGHT GAIN COMPARISON

Each test conducted at a location which is at equal range from each repeater site.

Test Site	Signal dBuV/RX (mean of 2 or 3 tests) Northstar	1975 Corydon	Δ (Northstar-1975 Corydon)
1	36.0	34.0	2.0
2	40.2	37.0	3.2
3	34.3	34.4	0
4	30.7	30.6	0.1
5	44.0	40.0	4.0
6	29.1	26.8	2.3
7	25.0	21.8	3.2
8	26.3	22.8	3.5
9	35.6	30.4	5.2

Mean Δ = 2.6 dB
But Northstar TX Power was 1.3 dB below 1975 Corydon.
Thus the apparent height gain = 2.6 + 1.3 = 3.9 dB.

APPENDIX 10

EGLI RECEIVED VOLTAGE CALCULATION

Egli's equation (4) (Propagation above 40 MC, Proc. IRE; 45, p. 1383-1391 (1957)) can be written as*:

$$P_{50} = K\left(\frac{h_t h_r}{d^2 f}\right)^2 P_t$$

where $K = 5.52 \times 10^{-12}$ for
h in ft.
d in mi.
f in MHz
P_t = ERP in watts

and $K = 4.289 \times 10^{-9}$ for
h in m
d in km

P_{50} here is defined as the power received between half-wave dipoles at 50% of locations. Thus

$$E_{50} = ZP_{50}^{\frac{1}{2}} \text{ where } z = 50 \text{ ohm RX input}$$

$$E_{50} \text{ (uV across 50 } \;) = 4.631 \times 10^2 \frac{h_t h_r}{d^2 f}(P_t)^{\frac{1}{2}} \text{ for dipole, h in m, d in km.}$$

$$\text{Aperture of quarter-wave whip} = \left(\frac{2\lambda}{\pi\, 4}\right)^2 = 2.533 \times 10^{-2}\,\lambda^2$$

$$\text{Aperture of half-wave dipole} = \frac{1.64\,\lambda^2}{4\pi} = 1.305 \times 10^{-1}\,\lambda^2$$

$$\therefore \text{ Relative power gain of whip} = \frac{2.533 \times 10^{-2}}{1.305 \times 10^{-1}} = 0.1941$$

$$\text{Thus } E_{50\Omega\,\text{whip}} = (0.1941)^{\frac{1}{2}} E_{50\Omega\,\text{dipole}} = 2.04 \times 10^2 \frac{h_t h_r}{d^2 f}(P_t)^{\frac{1}{2}} \text{uV}$$

* Egli's first equation on p. 1384 is correct only for dipole antennae. For isotropic antennae, the 95 constant would be 121.4.

$\therefore$ For the Northstar TX, h_t = 110m, h_r = 3m, f = 465 MHz,

P_t = 23.9 W (ERP), Egli predicts

$$E_{in}\ (dBuV/_{50\Omega}) = 57.0-40 \log d$$

For the 1975 Corydon TX, h_t = 55m, h_r = 3m, f = 465 MHz,

P_t = 32.6W, Egli predicts

$$E_{in}\ (dBuV/_{50\Omega}) = 52.3-49 \log d$$

The above predictions use a receiver height factor of 20 log h_r, not 10 log h_r as Egli recommends for $h_r \leq$ 30 ft. (9.14m). To correct to 10 log h_r, subtract 9.6 dB (= 10 log 9.14) from the above expected signals. RX line and matching losses of about 1.5 dB should also be subtracted. With these corrections, the expressions are:

Northstar: $E_{in}\ (dBuV/_{50\Omega}) = 45.9 - 40 \log d$

1975 Corydon: $E_{in}\ (dBuV/_{50\Omega}) = 41.2 - 40 \log d$

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