Serial No. OSU82-00175

FINAL REPORT
March 31,1984

STUDY ON THE MEASUREMENT, ANALYSIS AND FORECASTING OF THE ELECTROMAGNETIC FIELD ENVIRONMENT

(PHASE II)

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FOR
Department of Communications
Department of Supply and Services Contract
DSS Contract No. 23SU.36100-2-4212
McGill Reference No. 236-78
Covering the period August 1, 1983 to March 31,1984.

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STUDY ON THE MEASUREMENT, ANALYSIS AND FORECASTING OF THE ELECTROMAGNETIC FIELD ENVIRONMENT

(PART II)

(I). INTRODUCTORY STATEMENT

The present study involves the continuation of activities as outlined in Phase I of the study on the Measurement, Analysis, and Forecasting of the Electromagnetic Field Environment (1) supported by the Department of Communications (DOC) under DSS Contract No. 23SU.36100-2-4212, under the direction of Prof. T.J.F. Pavlasek at McGill University and Dr. J. Lebel of the Communications Research Centre (CRC) laboratories, Shirley Bay, Ottawa. Data processing, plotting and analysis was carried out by T. Banik, Research Assistant in the Department of Electrical Engineering at McGill University.

This report will present outdoor em field data obtained from the CRC's mobile unit. The mobile unit has the capacity to make rapid scans over a set of preselected frequencies, then record and store the field strength at each frequency and the location at which the measurement was taken. This report also presents the indoor em field data taken at two particular FM broadcast frequencies located inside a particular hi-rise downtown Montreal building, the McConnell Engineering Building located on the main campus of McGill University.

An analysis of the known locations of all the major AM, FM and TV transmitters in the Montreal area allows the prediction, using a simple free-space propagation model, of the approximate order of magnitude of the outdoor field levels for a receiving unit at grade level at the McConnell Building. These predicted field levels can then be used as a reference against which actual measurements may be compared. It should be noted that while the predicted field levels only account for the direct path wave (ignoring for the moment reflected and surface waves), the direct wave model is useful for establishing a reference datum for comparison with actual outdoor measurements provided by the mobile unit.

The outdoor field strength measurements provide insight and understanding of the microstructure of the outdoor em environment, while the indoor measurements indicate the manner in which the em microstructure penetrates into buildings. The knowledge and understanding of the EM environment microstructure inside and outside buildings is essential to ensure the satisfactory behaviour of sensitive electronic systems in the face of growing levels of EM fields due to broadcast and other systems.

The concern with indoor field strength measurements is not new. Recently, measurements in the 800-MHz range have been carried out on a variety of buildings by Cox, Murray,and Norris of AT&T Bell Laboratories (4,5) to determine the communications requirements of a proposed cellular mobile radio system. In the above study, a similar mobile unit was used as a fixed radiotelephone terminal which communicates with portable handheld transceivers. The received signal statistics can be modelled as a combination of small-scale quasi-stationary process (multipath) superimposed on a large-scale process (shadowing), which is similar to the models used in mobile radio propagation (5).

The main concern in the AT&T Bell Labs study is the degree of building attenuation which ultimately affects the cellular radio system performance and the objective is to ensure a sufficiently high field strength. However, in the present study, the performance of a communication system is not the key issue. Here, the objective is the opposite, namely to minimize field levels to protect electronic equipment.

Furthermore, our interest here addresses in principle the entire EM spectrum of the electromagnetic environment, and is not necessarily limited to a particular frequency range. However, as a practical necessity, only the outdoor and indoor measurements and analysis have been made of the rather strong EM fields created by local broadcast sources,in particular the AM, FM, and TV transmitters located in the city core. In further studies, field strength measurements will need to be made in other frequency ranges where strong em fields exist.

Previous studies of this nature (see reference (6), for example) have been concerned with the macrostructure for an entire metropolitan area, using measurements and their statistical analysis to estimate city wide probability of the prevalent field strength levels.

In the present study particular attention is being given to the actual morphology of the field and the statistical analysis of the probable strength over a small segment of an inner city area. It is therefore an investigation of the microstructure of fields.

Once the EM field levels inside and outside a specified building have been estimated from both indoor and outdoor data respectively, the building attenuation caused by the material properties of the building can be estimated. The building atenuation can be determined by the difference in the average outdoor and indoor rf power levels at a particular frequency.

The present case study is intended to furnish information relating to the microstructure environmment of a high density urban area, such as downtown Montreal. The microstructure em environment within a typical downtown hi-rise building, such as the McConnell Building is also investigated. The known AM, FM, and TV transmitters surrounding the city provide an ideal laboratory setting for the evaluation of both the macrostructure and the microstructure of the em environment. Figures (3.1.1) and (3.1.2) (p.10) depict the known city radiators in actual and schematic forms in relation to McGill University.

STATEMENT OF OBJECTIVES

Following are the main objectives of Phase II of the study on the "Measurement, Analysis and Forecasting of the Electromagnetic Field Environment" under way at McGill University:

-- To output the measured data from the March 1983 Outdoor Survey around the McGill University Campus recorded by the C.R.C. Mobile Field Scanning and Recording Unit;

-- To compare the outdoor survey measurements at grade level with free space values taking into consideration only the direct wave component in the computation of free space levels at all AM, FM, and TV broadcast frequencies;

-- To identify from the Outdoor Survey the most significant strong stations based on simple statistical processing of the outdoor data;

-- To compare the outdoor data measured at grade level with indoor data for a particular downtown building in order to estimate the degree of building attenuation at one FM frequency;

-- To suggest possible improvements in the methodology for further indoor measurements.

(II). REVIEW OF THE PROBLEM

The ambient electromagnetic (em) environment can be classified into the natural em environment and the man-made em environment. The natural em environment, as the name implies, comprises the em fields due to natural sources which may be of terrestrial or extra-terrestrial origin. The man-made em environment, on the other hand, comprises the em fields due to man-made radiators, which can be grouped into intentional and unintentional man-made radiators. It is the intentional man-made em environment that is most easily measured since the em fields associated with intentional radiators are of the highest magnitude of all classes of em radiators, this being particularly true in highly populated urban areas.

Over the past several decades, the growth of the man-made em environment has been such that present field levels due to such sources now exceed those due to natural sources by four to six orders of magnitude (2). Because of the growing number and density of rf transmitters in urban areas and the increasing magnitude of urban field levels in the rf portion of the em spectrum, concern has been expressed about the regulatory aspects of electromagnetic fields due to man-made radiators (see, for instance ref. 3) in the light of the possible electromagnetic susceptibility (ems) of sensitive electronic systems to the increasingly hostile e.m. environment. Although the vast majority of the public are exposed to power densities far below the most stringent standards anywhere in the world, some occupational groups, such as broadcast-staion workers and workers in the plastics and other industries who use RF heat sealers may be exposed to e.m. radiation levels that meet or exceed the present ANSI standard, which is now approximately 6 V/m from 50-500 MHz (3).

It was announced recently this year (1984) in the EMC Society Newsletter that a number of professionals in the field of electromagnetic compatibility (emc) have proposed that the name EMC be changed to E^3 - denoting Electromagnetc Environmental Effects. This indicates an increasing awareness and recognition of the importance of the environmental effects of electromagnetic fields, and particularly those fields created by man-made radiators.

To ensure the continuing protection of electronic devices from the em environment in which they are expected to operate would require ongoing, detailed monitoring and control of field levels simultaneously at many locations over the entire spectrum. This is clearly an impracticable task at this stage. Instead, the behaviour of the environment needs to be investigated and described in probabilistic terms to enable the prediction of the likelihood that the field exceeds a particular value. Based on such studies, it will be possible to postulate policies regarding ongoing measurement and monitoring. Evidently, this approach requires a large amount of measurement data to serve as a basis for the development of a reliable and meaningful model of the environment. Such measurements, after a certain amount of statistical processing, can then be compared against theoretical calculations to arrive at a cumulative probability distribution for expected field levels in a particular region at any given time.

As noted earlier, previous studies (6,7) have addressed themselves to the overall behaviour of a metropolitan region. The present study concerns itself with an evaluation of a small segment of a metropolitan area and attempts to examine whether it is appropriate to seek statistical prediction models which would take into consideration the structural form of the fields and also the behaviour when penetrating into buildings.

(III). ANALYSIS OF THE URBAN OUTDOOR EM ENVIRONMENT

(.1) Global Situation.

It is well known that the em environment in an urban area is dominated by the presence of AM, FM and TV transmitters which surround the service area. Figures (3.1.1) and (3.1.2) depict the actual and schematic transmitter locations for the Montreal area. The actual transmitter location diagram was obtained by identifying the major AM, FM, and TV transmitters on a large scale map of the island of Montreal (scale 1: 50 000). From this diagram, it is seen that the AM transmitters form an outer ring while the FM and TV transmitters form and inner ring of transmitters relative to the McGill University campus in downtown Montreal. Figure (3.1.1) thus allows the global representation of the em environment created by broadcast radio and tv transmitters. Figure (3.1.2) is a schematic representation of Figure (3.1.1). From this schematic diagram it can be visualized that due to larger transmitter distances and lower transmitter power, the AM transmitters would be expected to produce much weaker fields at the McGill campus than those produced by the surrounding FM or TV transmitters, which are closer to the McGill campus. The free-space propagation model will then be used as a basis for relating actual field measurments to the known rf transmitters and their respective locations relative to the McGill campus.

Table (3.3.1) gives a summary of the EM environment due to local broadcast transmitters based on the direct wave free space propagation model.

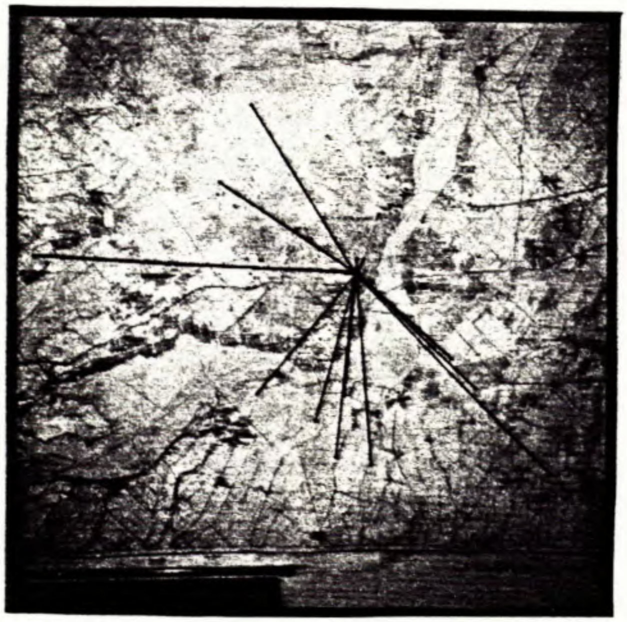


Figure (3.1.1). Photograph of AM, FM and TV Broadcast Transmitter locations in relation to McGill Campus.

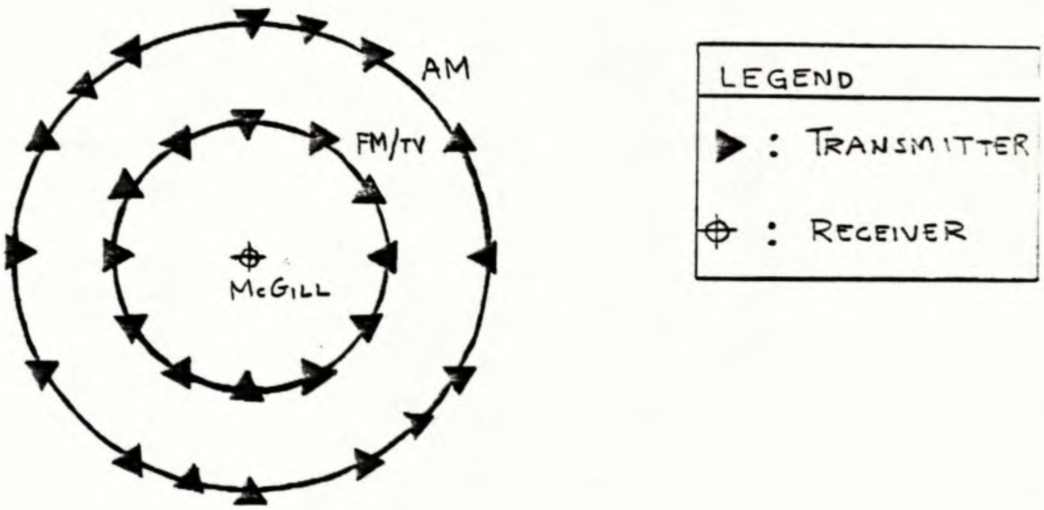


Figure (3.1.2). Schematic Model of the Montreal area Transmitters; Inner ring represents FM/TV transmitters; Outer ring represents AM transmitters.

(.2) Free Space Direct Wave Propagation Model.

The free space propagation model will be used to relate the received field strength (E_0) to the transmitter power (W) and the distance between transmitter and receiver (d). This model will include only the direct wave (1/r) component of the incident wave; the other components (ground wave, reflected wave, etc.) will not be included in the foregoing propagation model. The free space data will later be be used as a reference against actual field measurements made at grade level around the McGill campus in March 1983 by the mobile unit.

The following symbols will be used in the derivation of the received free space field strength due to a known transmitter:

h_1 = elevation of the transmit antenna above grade level,

$h_1 - h_2$ = the difference in height between the transmit and receive antennas,

x = horizontal distance between transmit and receive antennas,

d = pythagorean distance between transmit and receive antennas,

$G(\theta,\gamma)$ = the transmit antenna absolute gain, modified as appropriate by the radiation pattern in the direction of the direct ray path,

W = input power to transmitter,

P = radiated power density at distance d from the transmitter,

θ = angle of depression between transmitter and receiver,

ERP = effective radiated power of transmitter in the direction of the direct ray path,

E_0 = free-space field strength at distance d away from transmitter,

VCF = vertical correction factor.

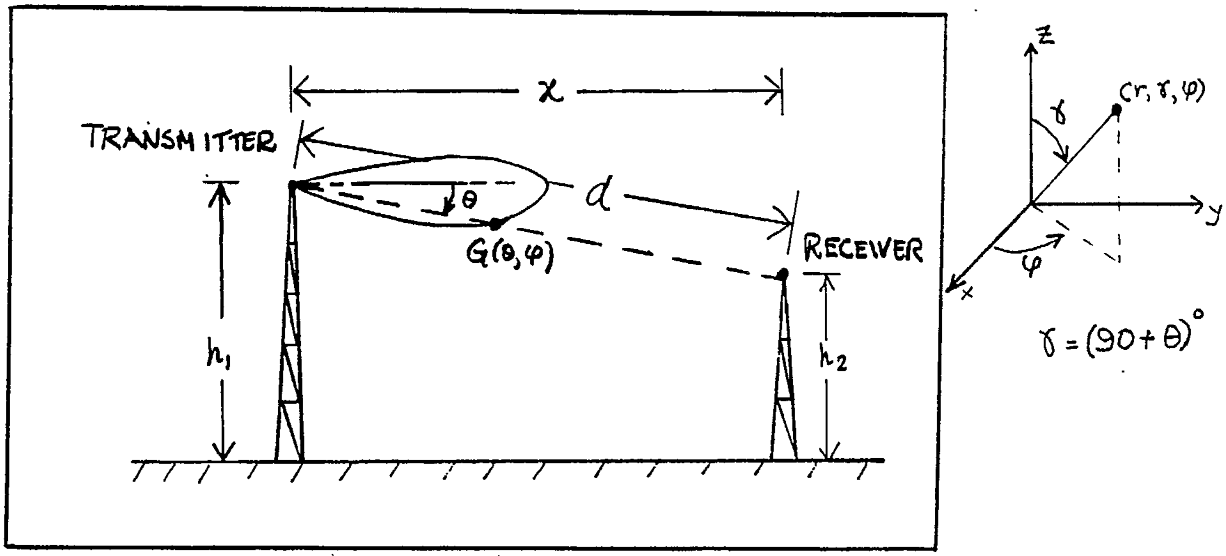


Figure (3.2.1). Geometry used in Free Space Direct Wave Model.

From figure (3.2.1) it can be seen that if $d \gg (h_1 - h_2)$, then $\theta \to 0$ and $h_1 \approx h_2$, so that the angle of depression becomes insignificant at large distances away from the transmitter. This will be the case for the AM transmitters, where the distance d can be approximated as,

$$d \approx x \qquad (3.1)$$

If d is comparable to $(h_1 - h_2)$, the angle of depression below the horizontal is significant, hence θ and d are obtained as follows:

$$\theta = \tan^{-1}((h_1-h_2)/x) \qquad (3.2)$$

$$d = x/\cos\theta \qquad (3.3)$$

Thus for the AM transmitters equation (3.1) is used, while equation (3.3) is used for the FM and TV transmitters.

We now derive a general formula for the received free space field strength. In the case of the FM and TV transmitters, the free space field strength will be multiplied by a vertical correction factor (VCF) which is obtained from the vertical radiation pattern of the FM/TV transmitter.

The effective radiated power (ERP) due to a transmitter with input power W and gain $G(\theta,\phi)$ is given by,

$$ERP = W*G(\theta,\phi) \qquad (3.4)$$

The radiated power density at distance d for a transmitter power of magnitude ERP is given by,

$$P = ERP/4\pi d^2 \qquad (3.5)$$

Assuming free-space propagation (η_0=120π) we have the following relation for the power density:

$$P = E_0{}^2/2\eta_0 \qquad (3.6)$$

where it is assumed that d is sufficiently large ($d \& \lambda/2\pi$) that only plane waves exist by virtue of,

$$E_0/H_0 = 120\pi = \eta_0 \qquad (3.7)$$

Then from equations (3.4)-(3.6), the free-space radiated electric field strength at distance d from the transmitter is given as,

$$E_0^2 = (W*G(\theta,\varphi)*\eta_0)/4\pi d^2$$
$$= 30*W*G(\theta,\varphi)/d^2 \qquad (3.8)$$

The final relation between received field strength and rf transmitter power is thus given as,

$$E_0 = (30*W*G(\theta,\varphi)/d^2)**0.5$$
$$E_0 = (1/d)*((30*W*G(\theta,\varphi))**0.5)$$
$$E_0 = (1/d)*((30*ERP)**0.5) \qquad (3.9)$$

The above model must be understood to represent an simplified version of the em environment as implied by assumptions (a) to (e) below. This model is used in order to provide numerical values of expected field levels from known AM/FM/TV transmitters (see table (3.3.1)) so that actual field measurements can be compared against free space values; any differences between the two will provide a means of estimating the effects of reflection and scattering from the ground, ionosphere, buildings, trees, and other obstacles, be they mobile or stationary.

Listed below are the assumptions made in the free space direct wave model.

Assumptions Used in the Direct Wave Free Space Propagation Model:

(a) isotropic receiving antenna ($G_R(\theta,\varphi) = 1$);

(b) the propagation medium is linear, homogeneous, isotropic, and time-invariant;

(c) the distance between transmitter and receiver is sufficiently large to ensure far-field behaviour, that is, no near-field coupling arises between the transmitter and receiver. This implies plane wave propagation in free space;

(d) the only coupling mechanism between the transmitter and receiver is due to direct wave radiation in free space; inductive coupling or ground wave conduction mechanisms are assumed to be negligible. Ground wave or reflected wave propagation along the earth's surface or ionosphere respectively are neglected; however in certain specific frequency bands (HF,MF,VHF,UHF) the ground wave or reflected wave components are quite significant, hence they must be added as phasors to obtain the resultant field. Such a model incorporating only a single reflected wave component plus a single ground wave component would be of little use however since the model does not include the contributions from a host of multiple reflections arising from tall downtown buildings, trees, vehicles, etc., which undoubtedly affect the resultant field strength measured in an urban area. For this reason, only the direct wave component is included in the free space propagation model. The absolute difference between the measured field pattern and the predicted direct wave pattern can thus be understood to represent the contribution of all ground wave and multiple reflected wave components arising from a host of interference effects as described above;

(e) the received field is modelled as the result of free- space electromagnetic wave propagation from a single intentional radiator, such as a licensed broadcast transmitter with known characteristics. Co-channel interference, harmonic interference, and spurious emissions from nearby unintentional radiators are not accounted for;

(f) The transmitting antenna has 100% efficiency, that is, the total radiated power in all directions is equal to the input power to the antenna.

(.3) Computation of Free Space Field Levels.

Using the above model, free space direct wave field strengths at the McGill Campus were computed given the required data. The data needed to compute the direct wave component of the received field strength are as follows:

a. distance (d) between transmitting and receiving antennas,
b. input power to transmitter (W),
c. horizontal radiation pattern to obtain the gain $G(\varphi)$ for the AM stations,
d. difference in heights between transmit and receive antennas to obtain the angle of depression, θ for the FM/TV stations,
e. vertical radiation pattern to obtain the boresight gain and the VCF for the FM/TV stations.

In the following analysis, it will be assumed that the height of the receiving antenna (h_2) is 3 meters above ground level. This value corresponds to the approximate height of the antenna of the on top of the C.R.C. mobile field recording unit. The mobile unit was used obtain a data bank of outdoor grade level field strength measurements at several AM, FM and TV broadcast stations around the periphery of the McGill University campus in downtown Montreal.

The calculations of the received field strength for various licensed broadcasting stations in the AM, FM and TV bands are summarized below in table (3.3.1). The major source of error in the computed values of E_0 arise out of the uncertainty in the distances. The distances were estimated from a Montreal area map of scale 1:50 000. The AM distances, being much larger than the FM/TV distances, were obtained directly from the map. The distances coresponding to the FM and TV stations require a more careful estimate of the map distance (x), since a small error in the map distance will introduce a proportionately larger error in E_0 as the distances between transmitter and receiver are much shorter for FM and TV stations than they are for the AM stations. For this reason, the FM/TV values of E_0 in table (3.3.1) should be regarded as being slightly less accurate than the AM values.

Transmitter data and transmit antenna radiation patterns for a few of the strongest stations are given in Appendix B. These radiation patterns, together with the large scale map, were used extensively in gathering the appropriate parameters (see equation (3.9)) for computing the free space field strengths, which are tabulated in the last two columns of table (3.3.1) below, in linear (V/m) and logarithmic (dBuV/m) units.

Table (3.3.1). Predicted Direct Wave Free Space Field Levels at the McGill Campus due to Montreal Broadcast Transmitters.

AM TRANSMITTERS:

STN	f(kHz)	x(km)	W(kW)	EIF(mV/m) (§ 1 mile)	Field Gain	E_0(mV/m) ---(§ x km)---	E_0(dBuV/m)
CFCF	600	16.5	5.0	452.0	1.78	78.0	97.9
CBF	690	13.5	50.0	1800.0	1.00	213.3	106.6
CKAC	730	31.0	50.0	1340.0	1.36	94.1	99.5
CJAD	800	28.5	50.0	1570.0	1.27	119.9	101.0
CKVL	850	12.5	50.0	1158.0	1.06	157.1	103.9
CBM	940	13.5	50.0	1830.0	1.05	227.7	107.1
CKGM	980	16.0	10.0	585.0	1.13	66.1	96.4
CHRS	1090	29.0	10.0	569.0	1.00	31.4	89.9
CJMS	1280	20.0	50.0	1505.0	1.86	223.9	107.0
CFMB	1410	17.0	10.0	700.0	1.71	112.7	101.0
CKO	1470	20.0	50.0	1570.0	0.54	66.6	96.5
CKLM	1570	17.0	50.0	1765.0	1.05	174.4	104.8

FM TRANSMITTERS:

STN	f(MHz)	x(km)	h_1 (m)	θ (deg)	VCF	ERP (kW)	d (m)	E_0 (mV/m)	E_0 (dBuV/m)
CFQR	92.5	0.9	298	18.1	.18	41.4	946	212.1	106.5
CBM	93.5	0.9	251	15.4	.16	24.6	933	147.3	103.4
CKMF	94.3	0.9	298	18.1	.18	41.4	946	212.1	106.5
CJFM	95.9	0.9	298	18.1	.18	41.2	946	211.5	106.5
CKOI	96.9	1.1	217	11.0	.45	307.0	1121	1218.0	121.7
CHOM	97.7	0.9	298	18.1	.18	41.2	946	211.5	106.5
CBF	100.7	0.9	251	15.4	.16	100.0	933	297.0	109.5
CINQ	102.3	1.2	46	2.0	.96	0.04	1200	28.1	88.9
CFGL	105.7	15.3	121	0.4	.98	100.0	16000	400.5	112.2
CITE	107.3	1.4	112	4.5	.50	100.0	1404	1249.0	121.9

TV TRANSMITTERS:

STN	audio f(MHz)	video f(MHz)	h_1 (m)	θ (deg)	VCF	ERP(kW) (audio)	d (m)	E_0(audio) (mV/m)	(dBuV/m)
CBFT	59.75	55.25	278	17.0	.04	100.0	941	73.6	97.3
CBMT	87.75	83.25	252	15.4	.16	100.0	933	297.0	109.5
CFTM	197.75	193.25	296	18.0	.16	325.0	946	528.1	114.4
CFCF	209.75	205.25	296	18.0	.16	325.0	946	528.1	114.4
CIVM	493.75	489.25	191	11.8	.12	242.0	919	351.8	110.9

COMMENTS FOR TABLE (3.3.1):

- 1. The antenna gain for the FM/TV transmitters was taken to be unity at the boresight ($G(\theta = 0) = 1$) except in certain cases where the gain was specified to be greater than one;

- 2. The FM/TV antennas radiate isotropically in the horizontal plane, that is, $G(0,\varphi) = G(0)$;

- 3. The antenna gain for the AM transmitters was obtained directly from the corresponding horizontal radiation pattern in the direction towards the McGill Campus in downtown Montreal, using the given effective isotropic field (EIF) at 1 mile. The "free space" equivalent field at the distance x (station to McGill) was then calculated in terms of 1/r dependence. In Appendix (C) a more detailed discussion is given in terms of propagation models which consider ground wave effects.

Since the distances between the AM transmitters and the McGill campus are large as compared to ($h_1 - h_2$), and since ($h_1 - h_2$) is essentially zero, then the angle of depression has no significance.

- 4. In the case of AM transmitters, the power quoted is the input into the antenna system, whereas in the FM-TV stations, the ERP is indicated. In that case, the ERP corresponds to the centre of the main beam of the antennas;

- 5. The FM and TV transmitters are omnidirectional in the horizontal plane; as described in the text the expected electric field at a given distance and depression angle is calculated (assuming free-space propagation) from the ERP and the depression angle;

- 6. In the case of the TV station shown in Table (3.3.1), the audio and video carrier frequencies are given. The ERP and predicted fields are for the audio carrier because the measurements (reported further in Table (5.5.1)) were made at the audio carrier frequency.

The reasons for this are:

6.1 The average video power varies continually in time (over the normal 4 MHz video bandwidth and over narrower bandwidths), depending on the content of the video signal.

6.2 The audio carrier power is relatively stable (because FM modulation is used).

6.3 The audio carrier provides a means of determining indirectly by how many dB the video signal level is located below its calculated value, assuming a good amplitude correlation (which is sensible) between the video and the audio carriers. A simple correlation is by the power level difference between the audio and video ERPs. When deriving statistics from the measurements of the electric fields due to the audio carrier, the condition of perfect coherence between the two carriers may not be required.

6.4 From published tables, it is possible to make conversions from audio power to video power. A certain degree of uncertainty remains, in view of the fact that the published video carrier power may correspond to either (which one is at times unspecified) the maximum video power or the average video power. Also, variations in time of the average video carrier may add to the uncertainty.

6.5 From the bottom table on page B-1, one finds:

Station	Video ERP (kW)	Audio ERP (kW)	dB difference
CBFT	100.0	10.0	10.0
CBMT	100.0	15.0	8.2
CFTM	325.0	160.0	3.1
CFCFTV	325.0	160.0	3.1
CIVM	1212.0	242.0	7.0

6.6 Measuring the peak video power of the signal (which is relatively stable with respect to the magnitude (power) of the audio signal) cannot be accomplished with the equipment currently in use. Therefore a clearly desirable future measurement objective should be to develop equipment to measure the peak video power, in order to measure the video power level directly without relying on the audio to video conversion with its inherent uncertainty.

In the construction of table (3.3.1), information about each broadcast transmitter (location, input power, antenna gain, antenna height) is required to compute the free space values. Distance data were obtained using an expanded scale map (1: 50 000) of the island of Montreal; transmitter powers and transmit antenna radiation patterns were supplied for most stations.

Table (3.3.2) and comments summarize the operations performed in computing the predicted free space field strengths given in the last two columns of table (3.3.1).

Table (3.3.2). Procedure Used to Calculate Free Space Field Strengths.

STEP	f/BAND	OUTPUT VARIABLE	INPUT VARIABLE(S)	EQUATION(S) USED
1	AM	x, φ	--	Obtained from a large scale city map;
	FM/TV	x		same as for AM;
2	AM	d	x	(3.1)
	FM/TV	θ	$x, (h_1-h_2)$	(3.2)
	FM/TV	d	x, θ	(3.3)
3	AM	$G(0,\varphi)$	φ	Horizontal Radiation Pattern;
	FM/TV	VCF	θ	Vertical Radiation Pattern or use (3.14)/(3.15);
	FM/TV	$G(0)$	--	Vertical Radiation Pattern only;
4	AM	ERP	$W, G(0,\varphi)$	(3.4)
	FM/TV	ERP	$W, G(0)$	(3.4)
5	AM	E_0	ERP, d	(3.9)
	FM/TV	E_0	ERP, d, VCF	(3.12)
6	AM/FM/TV	E_0 (dBuV/m)	E_0	(3.13)

According to equation (3.9) the free space field strength for an AM transmitter is given by,

$$E_0 = (1/d)*((30*W*G(0,\varphi))**0.5) \qquad (3.11)$$

where $G(0,\varphi)$ is the gain of the AM transmit antenna in the direction of the direct ray path, in this case towards the city with respect to the north pole.

In the case of FM and TV transmitters, the free space direct wave field strength is given by,

$$E_0 = (VCF/d)*((30*W*G(0))**0.5) \qquad (3.12)$$

where G(0) is the boresight gain of the FM/TV antenna. It is assumed that FM/TV antenna radiates isotropically in the γ-plane hence the gain is not a function of γ. Since vertical plane radiation at VHF must be minimized as much as possible to avoid wastage of rf energy, the main lobe is shaped to radiate most of the energy in a narrow beamwidth along the horizon (θ = 0). This technique maximizes the range of the FM or TV transmitter.

The VCF is the vertical correction factor; it can be obtained from the vertical radiation pattern or may be evaluated using an appropriate analytical scheme, for example, spherical trigonometry.

In all field strength computations, the AM/FM/TV receiving antenna is assumed to be located at the McGill campus, at a height of 3 meters above grade level, since the outdoor survey field measurements were made at approximately this height above the ground with the CRC mobile unit.

The electric field strength can be expressed in dBuV/m as,

$$E_0(\text{dBuV/m}) = 20\log_{10}(E_0(\text{uV/m})) \qquad (3.13)$$

For the FM and TV transmitters, the distances involved are much shorter, hence the effect of the angle of depression is quite significant. This angle may be computed using equation (3.2) or, alternatively may be estimated using simple surveying equipment if the transmitting antenna is within sight from the receiving antenna. The former method was used in determining θ since the transmitter heights were supplied. The horizontal distances (x) from the McGill campus were estimated from a large city map (scale 1: 50 000). However, it should be noted that most of the Montreal area FM/TV transmitters are located on top of Mount Royal which is within direct view from the McGill Campus. The vertical radiation pattern expresses the field strength at a particular depression angle as a fraction of the field strength along the horizon. This fraction can be used as the numerical value of the VCF. Then, provided that the angle of depression is known, the effect of the angle of depression can be determined simply by multiplying the free-space value by the VCF.

Although it is preferable to use the vertical radiation patterns when they are available, an empirical, experimentally based formula for the VCF can be helpful when such patterns are not available. The VCF has been expressed analytically based on experimental data in an earlier urban EM environment study (6), the formula of which is repeated here for convenience:

$$VCF = 10**(-(.015\theta + .175)) \qquad \theta > 5 \text{ degrees} \qquad (3.14)$$

$$VCF = 10**(-.05\theta) \qquad \theta < 5 \text{ degrees} \qquad (3.15)$$

where θ is the angle of depression between the transmitting and receiving antennas.

The received field strength E_0 at an angle θ below the horizon can then be obtained from the following expression:

$$E_0 = E_0' * VCF \qquad (3.16)$$

where E_0' is the free space field strength along the horizon.

This section has described a possible procedure for predicting the free-space field strength for the AM, FM, and TV transmitters. In actual fact the data given in Table (3.3.1) used the above procedure for the FM and TV stations only. In the case of the AM stations the field was predicted using the horizontal radiation patterns and the given Effective Isotropic Field at one mile, (EIF).

(IV). DATA PROCESSING AND MANAGEMENT

(.1) Overview of McGill Computer Facilties.

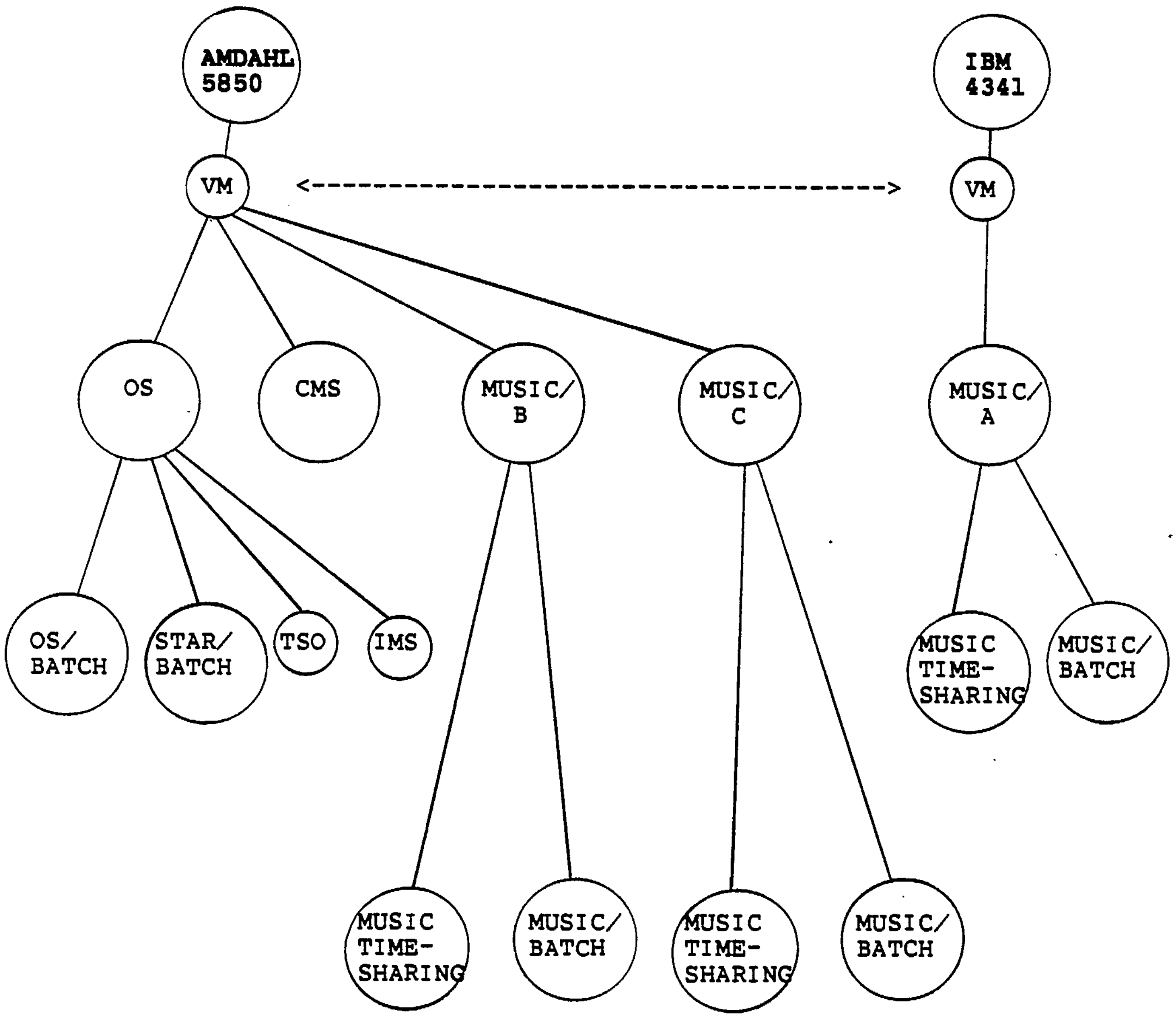
The hardware environment of the McGill University Computing Centre consists of an AMDAHL 5850 (with a 5860 accelerator) with 24 megabytes of main storage and 20 input/output channels, and an IBM 4341 Model 2, with 8 megabytes main storage and 6 input/ouput channels. A wide variety of I/O peripherals is provided for accessing the system.

The operating systems which are supported include VM/SP (Virtual Machine System Product), MVS/SP (Multiple Virtual Storage System Product) IBM release 3.8 (called "OS" for short), and MUSIC/SP (McGill University System for Interactive Computing System Product). The two computers are linked by VM/Pass-Through and VM/RCCS. Figure (4.1.1) shows the various operating systems and their relation to the hardware.

These mainframe facilties were available for this project, especially for the processing of the outdoor measurements transferred by magnetic tape from C.R.C. to McGill.

The McGill University System for Interactive Computing (MUSIC, for short) was used extensively in developing data processing software used for creating data files, for plotting the data, and for elementary statistical processing. The MUSIC system provides a multiuser interactive environment that allows communication with the mainframe from a variety of remote terminals. Batch processing processing can also be handled through the MUSIC system, since a user may transfer the processing from MUSIC to MVS. The latter OS is often preferred by users with large amounts of data, as batch processing is about three to four times cheaper than running under the available interactive system.

Figure (4.1.1). Overview of McGill Mainframe Computing Facilities (10).



(.2) Data Processing Software Developed.

In order to read, process, statistically analyze and produce graphical plots from the measured data, a number of programs had to be developed and the MUSIC system was used for this purpose. In this section, the software that was developed for carrying out the above tasks will be described with reference to the mainframe computing facilities described earlier.

The four principal programs developed were:

(1) READ.DOC4 - to manage the reading of the tapes,

(2) BOB.MAIN - for selecting and managing the recorded data by creating appropriate data files,

(3) DOC.PLOT - for controlling the data to be plotted and the scale parameters,

(4) DOC.STAT - for generating simple statistical evaluation of the measured data.

A number of minor utility programs were also developed such as for tapedumping, simple plotting, etc., using the available IBM utility programs and MUSIC subroutines, respectively. Some details of the above four programs are described below.

READ.DOC4

The ASCII coded data stored on tape was transferred onto disk using IBM utility programs. A program involving the use of IBM tape reading programs was written in Job

Control Language (JCL) in order to access the MVS Operating System (OS). The READ.DOC4 program performs this task. The raw data is stored in a single file (MCGILL.AFT,MCGILL.UHF,etc.) containing all the original ASCII characters under the same data set names as those stored on tape. The measurement data can thus be accsessed from MUSIC once the appropriate disk file is created.

BOB.MAIN

Processing of the data is possible after the data has been transferred to the MUSIC system, for which three different programs were developed for carrying out three principle data processing tasks. The BOB.MAIN program creates data files containing the field strength and position information for a particular station along a selected street. This interactive program requires as input the data as transferred to MUSIC using READ.DOC4. The program requests the user to input the station name, frequency, polarization, modulation, street of travel, and the intersecting street, at the start. It then searches for the data corresponding to the selected station by comparing record types. For example, record type six (6) defines a street and intersecting street, record type seven (7) contains starting and ending distances as well as field data for the first twenty (20) stations (there are forty stations in total counting one station for each polarization), record type seventeen (17) is a continuation of the field strength data for the remaining twenty stations. Once the field strength data has been identified for the chosen station, polarization, street and intersecting street, the program copies the position and field strength data into a MUSIC file, then closes the file and assigns a name to the file. The program then asks if any further data is needed for other stations; if so, a rewind is performed in order to re-initialize the pointer for further processing. If no further data is required, the program stops execution, and no further processing is done. The program is fully interactive on the MUSIC system and several data files were created in the above manner in order to isolate the measurement data for any station on any street. A sample edit session with BOB.MAIN and the corresponding output file created are given in figures (4.2.1) and (4.2.2) respectively.

Figure (4.2.1). Sample Edit Session with BOB.MAIN.

```
MAIN   = 000A3E
STDAT  = 000520
POSFLD = 000554
FLDCON = 0003A0
006E60 BYTES USED
EXECUTION BEGINS
ENTER STATION:
?
ckoi.vf
ENTER STATION FREQUENCY IN KHZ:
?
96900
ELECTRIC FIELD STRENGTH VS POSITION
STATION: CKOI.VF      ARRAY POSITION: 19
FREQUENCY (KHZ):  96900.00    WAVELENGTH (M):0.310E+01
ENTER THE DESIRED STREET OF TRAVEL (=TRAVST):
?
biology road
ENTER THE DESIRED INTERSECTING STREET (=INTST):
?
penfieldgate
 6A    42134410426   112417 UNIVERSITY                   SHERBROOKE
 6A                  063410 PINE                         UNIVERSITY
 6A                  043594 PEEL                         PINE
 6A                  007813 MCINTYRE                     PEEL
  A                  019965 DRUMMOND                     MCINTYRE
 6A                  011921 PENFIELD                     DRUMMOND
 6A                  019719 PEEL                         PENFIELD
 6A                  027391 SHERBROOKE                   PEEL
 6A    84144434700   133459 MCTAVISH                     PENFIELD
 6A   227144753125   024615 PINE                         MCTAVISH
 6A   272144846893   010615 PEEL                         PINE
 6A   3411450 9879   022698 PENFIELD                     PEEL
 6A    1615 528119   020650 BIOLOGY ROAD               . MILTON
 6A   593151810307   037250 SHERBROOKE                   BIOLOGY
 6A   694152022189   014499 MCTAVISH                     SHERBROOKE
 6A   891152420869   029638 PENFIELD                     MCTAVISH
 6A 101415264955 9   026773 BIOLOGY ROAD                 PENFIELDGATE
THE DESIRED STREETS HAVE BEEN FOUND
STREET:  BIOLOGY ROAD
INTERSECTING STREET:  PENFIELDGATE
END OF THE FIELD/POSITION DATA FOR THE DESIRED STREET
MORE DATA NEEDED FOR STATION  CKOI.VF  (YES OR NO) ?
?
no
END OF DATA FOR STATION:  CKOI.VF
DATA REQUIRED FOR ANY OTHER STATIONS?
?
no
STOP          0
```

Figure (4.2.2). Output File Created by BOB.MAIN.

ELECTRIC FIELD STRENGTH VS POSITION
STATION: CKOI.VF ARRAY POSITION: 19
FREQUENCY (KHZ): 96900.00 WAVELENGTH (M):0.310E+01
STREET: BIOLOGY ROAD
INTERSECTING STREET: PENFIELDGATE

POSITION(KM)	FIELD(DBUV/M)	FIELD(V/M)	FIELD(W/M**2)	FIELD(MW/CM**2)
0.00086	118.3	0.822	0.179E-02	0.179E-03
0.00213	114.7	0.543	0.783E-03	0.783E-04
0.00365	113.8	0.490	0.636E-03	0.636E-04
0.00535	109.6	0.302	0.242E-03	0.242E-04
0.00637	108.3	0.260	0.179E-03	0.179E-04
0.00760	107.5	0.237	0.149E-03	0.149E-04
0.00962	108.7	0.272	0.197E-03	0.197E-04
0.01262	110.1	0.320	0.271E-03	0.271E-04
0.01575	102.8	0.138	0.505E-04	0.505E-05
0.01890	94.1	0.051	0.682E-05	0.682E-06
0.02141	106.3	0.207	0.113E-03	0.113E-04
0.02368	107.7	0.243	0.156E-03	0.156E-04
0.02603	111.9	0.394	0.411E-03	0.411E-04
0.02857	105.5	0.188	0.941E-04	0.941E-05
0.03109	108.3	0.260	0.179E-03	0.179E-04
0.03323	105.0	0.178	0.839E-04	0.839E-05
0.03480	107.2	0.229	0.139E-03	0.139E-04
0.03641	99.7	0.097	0.248E-04	0.248E-05
0.03796	101.8	0.123	0.401E-04	0.401E-05
0.03992	99.6	0.095	0.242E-04	0.242E-05
0.04200	101.1	0.114	0.342E-04	0.342E-05
0.04375	104.3	0.164	0.714E-04	0.714E-05
0.04565	106.0	0.200	0.106E-03	0.106E-04
0.04757	104.8	0.174	0.801E-04	0.801E-05
0.04944	109.8	0.309	0.253E-03	0.253E-04
0.05110	106.8	0.219	0.127E-03	0.127E-04
0.05285	112.1	0.403	0.430E-03	0.430E-04
0.05445	107.4	0.234	0.146E-03	0.146E-04
0.05608	102.4	0.132	0.461E-04	0.461E-05
0.05768	103.4	0.148	0.580E-04	0.580E-05
0.05919	95.9	0.062	0.103E-04	0.103E-05
0.06065	107.2	0.229	0.139E-03	0.139E-04
0.06192	105.6	0.191	0.963E-04	0.963E-05
0.06318	104.3	0.164	0.714E-04	0.714E-05
0.06457	104.6	0.170	0.765E-04	0.765E-05
0.06626	106.6	0.214	0.121E-03	0.121E-04
0.06790	107.4	0.234	0.146E-03	0.146E-04
0.06925	107.4	0.234	0.146E-03	0.146E-04
0.07099	105.1	0.180	0.858E-04	0.858E-05
0.07301	112.8	0.437	0.505E-03	0.505E-04
0.07484	108.4	0.263	0.184E-03	0.184E-04
0.07701	107.6	0.240	0.153E-03	0.153E-04
0.07936	114.4	0.525	0.731E-03	0.731E-04
0.08187	94.2	0.051	0.698E-05	0.698E-06
0.08457	102.0	0.126	0.420E-04	0.420E-05
0.08643	112.6	0.427	0.483E-03	0.483E-04
0.08764	111.1	0.359	0.342E-03	0.342E-04
0.08899	107.2	0.229	0.139E-03	0.139E-04
0.09071	107.0	0.224	0.133E-03	0.133E-04

0.09240	108.5	0.266	0.188E-03	0.188E-04
0.09411	111.4	0.372	0.366E-03	0.366E-04
0.09587	111.8	0.389	0.401E-03	0.401E-04
0.09735	112.5	0.422	0.472E-03	0.472E-04
0.09895	112.3	0.412	0.450E-03	0.450E-04
0.10047	111.9	0.394	0.411E-03	0.411E-04
0.10194	110.9	0.351	0.326E-03	0.326E-04
0.10359	111.1	0.359	0.342E-03	0.342E-04
0.10577	112.3	0.412	0.450E-03	0.450E-04
0.10802	100.8	0.110	0.319E-04	0.319E-05
0.11041	115.3	0.582	0.899E-03	0.899E-04
0.11283	102.3	0.130	0.450E-04	0.450E-05
0.11476	111.2	0.363	0.350E-03	0.350E-04
0.11648	109.3	0.292	0.226E-03	0.226E-04
0.11831	109.7	0.305	0.248E-03	0.248E-04
0.12012	109.1	0.285	0.216E-03	0.216E-04
0.12190	111.4	0.372	0.366E-03	0.366E-04
0.12392	99.2	0.091	0.221E-04	0.221E-05
0.12590	95.9	0.062	0.103E-04	0.103E-05
0.12776	100.4	0.105	0.291E-04	0.291E-05
0.12963	98.9	0.088	0.206E-04	0.206E-05
0.13141	104.8	0.174	0.801E-04	0.801E-05
0.13310	107.2	0.229	0.139E-03	0.139E-04
0.13459	106.7	0.216	0.124E-03	0.124E-04
0.13595	114.7	0.543	0.783E-03	0.783E-04
0.13721	113.9	0.495	0.651E-03	0.651E-04
0.13854	113.4	0.468	0.580E-03	0.580E-04
0.14009	112.2	0.407	0.440E-03	0.440E-04
0.14175	113.6	0.479	0.608E-03	0.608E-04
0.14306	108.2	0.257	0.175E-03	0.175E-04
0.14432	113.8	0.490	0.636E-03	0.636E-04
0.14524	109.6	0.302	0.242E-03	0.242E-04
0.14595	111.1	0.359	0.342E-03	0.342E-04
0.14669	109.3	0.292	0.226E-03	0.226E-04
0.14723	112.6	0.427	0.483E-03	0.483E-04
0.14840	108.1	0.254	0.171E-03	0.171E-04
0.14944	108.3	0.260	0.179E-03	0.179E-04
0.15038	105.1	0.180	0.858E-04	0.858E-05
0.15130	108.1	0.254	0.171E-03	0.171E-04
0.15231	103.0	0.141	0.529E-04	0.529E-05
0.15324	104.7	0.172	0.783E-04	0.783E-05
0.15433	102.3	0.130	0.450E-04	0.450E-05
0.15545	97.4	0.074	0.146E-04	0.146E-05
0.15645	105.9	0.197	0.103E-03	0.103E-04
0.15732	99.0	0.089	0.211E-04	0.211E-05
0.15841	101.2	0.115	0.350E-04	0.350E-05
0.15935	98.5	0.084	0.188E-04	0.188E-05
0.16038	104.4	0.166	0.731E-04	0.731E-05
0.16141	97.7	0.077	0.156E-04	0.156E-05
0.16244	92.9	0.044	0.517E-05	0.517E-06
0.16365	105.2	0.182	0.878E-04	0.878E-05
0.16480	103.0	0.141	0.529E-04	0.529E-05
0.16619	95.3	0.058	0.899E-05	0.899E-06
0.16749	102.8	0.138	0.505E-04	0.505E-05
0.16849	108.6	0.269	0.192E-03	0.192E-04

0.16963	105.6	0.191	0.963E-04	0.963E-05
0.17068	99.9	0.099	0.259E-04	0.259E-05
0.17183	106.5	0.211	0.118E-03	0.118E-04
0.17291	107.2	0.229	0.139E-03	0.139E-04
0.17415	101.1	0.114	0.342E-04	0.342E-05
0.17507	103.3	0.146	0.567E-04	0.567E-05
0.17610	106.7	0.216	0.124E-03	0.124E-04
0.17684	107.7	0.243	0.156E-03	0.156E-04
0.17744	99.2	0.091	0.221E-04	0.221E-05
0.17832	106.2	0.204	0.111E-03	0.111E-04
0.17919	99.5	0.094	0.236E-04	0.236E-05
0.18027	105.7	0.193	0.986E-04	0.986E-05
0.18122	105.7	0.193	0.986E-04	0.986E-05
0.18210	105.3	0.184	0.899E-04	0.899E-05
0.18347	106.3	0.207	0.113E-03	0.113E-04
0.18455	104.0	0.158	0.666E-04	0.666E-05
0.18545	100.6	0.107	0.305E-04	0.305E-05
0.18627	104.5	0.168	0.748E-04	0.748E-05
0.18736	95.1	0.057	0.858E-05	0.858E-06
0.18835	106.0	0.200	0.106E-03	0.106E-04
0.18928	101.7	0.122	0.392E-04	0.392E-05
0.19043	99.9	0.099	0.259E-04	0.259E-05
0.19179	99.6	0.095	0.242E-04	0.242E-05
0.19300	106.4	0.209	0.116E-03	0.116E-04
0.19385	99.2	0.091	0.221E-04	0.221E-05
0.19485	108.5	0.266	0.188E-03	0.188E-04
0.19586	95.7	0.061	0.986E-05	0.986E-06
0.19660	104.5	0.168	0.748E-04	0.748E-05
0.19751	96.1	0.064	0.108E-04	0.108E-05
0.19823	105.7	0.193	0.986E-04	0.986E-05
0.19937	102.4	0.132	0.461E-04	0.461E-05
0.20031	105.6	0.191	0.963E-04	0.963E-05
0.20132	108.6	0.269	0.192E-03	0.192E-04
0.20230	109.9	0.313	0.259E-03	0.259E-04
0.20346	107.9	0.248	0.164E-03	0.164E-04
0.20458	106.3	0.207	0.113E-03	0.113E-04
0.20591	100.9	0.111	0.326E-04	0.326E-05
0.20735	108.2	0.257	0.175E-03	0.175E-04
0.20834	108.6	0.269	0.192E-03	0.192E-04
0.20972	90.8	0.035	0.319E-05	0.319E-06
0.21090	106.2	0.204	0.111E-03	0.111E-04
0.21184	92.9	0.044	0.517E-05	0.517E-06
0.21272	102.3	0.130	0.450E-04	0.450E-05
0.21369	99.1	0.090	0.216E-04	0.216E-05
0.21510	103.6	0.151	0.608E-04	0.608E-05
0.21643	101.9	0.124	0.411E-04	0.411E-05
0.21809	98.7	0.086	0.197E-04	0.197E-05
0.21927	98.7	0.086	0.197E-04	0.197E-05
0.22056	101.9	0.124	0.411E-04	0.411E-05
0.22212	102.5	0.133	0.472E-04	0.472E-05
0.22382	102.7	0.136	0.494E-04	0.494E-05
0.22545	94.8	0.055	0.801E-05	0.801E-06
0.22692	94.2	0.051	0.698E-05	0.698E-06
0.22838	100.7	0.108	0.312E-04	0.312E-05
0.22965	100.1	0.101	0.271E-04	0.271E-05

0.23069	101.4	0.117	0.366E-04	0.366E-05
0.23105	98.9	0.088	0.206E-04	0.206E-05
0.23263	96.8	0.069	0.127E-04	0.127E-05
0.23416	103.1	0.143	0.542E-04	0.542E-05
0.23532	102.4	0.132	0.461E-04	0.461E-05
0.23642	89.3	0.029	0.226E-05	0.226E-06
0.23719	105.9	0.197	0.103E-03	0.103E-04
0.23809	97.5	0.075	0.149E-04	0.149E-05
0.23905	98.3	0.082	0.179E-04	0.179E-05
0.24004	93.9	0.050	0.651E-05	0.651E-06
0.24120	94.8	0.055	0.801E-05	0.801E-06
0.24208	97.7	0.077	0.156E-04	0.156E-05
0.24318	96.5	0.067	0.118E-04	0.118E-05
0.24435	95.2	0.058	0.878E-05	0.878E-06
0.24567	99.3	0.092	0.226E-04	0.226E-05
0.24770	103.5	0.150	0.594E-04	0.594E-05
0.25008	99.5	0.094	0.236E-04	0.236E-05
0.25295	86.8	0.022	0.127E-05	0.127E-06
0.25580	95.6	0.060	0.963E-05	0.963E-06
0.25888	98.0	0.079	0.167E-04	0.167E-05
0.26235	92.2	0.041	0.440E-05	0.440E-06
0.26585	97.5	0.075	0.149E-04	0.149E-05
0.26911	95.8	0.062	0.101E-04	0.101E-05
0.27251	94.2	0.051	0.698E-05	0.698E-06
0.27580	95.6	0.060	0.963E-05	0.963E-06
0.27884	95.4	0.059	0.920E-05	0.920E-06
0.28183	92.5	0.042	0.472E-05	0.472E-06
0.28466	100.7	0.108	0.312E-04	0.312E-05
0.28755	94.5	0.053	0.748E-05	0.748E-06
0.29057	95.7	0.061	0.986E-05	0.986E-06
0.29376	91.6	0.038	0.383E-05	0.383E-06
0.29695	98.0	0.079	0.167E-04	0.167E-05
0.29988	97.6	0.076	0.153E-04	0.153E-05
0.30279	98.8	0.087	0.201E-04	0.201E-05
0.30522	87.4	0.023	0.146E-05	0.146E-06
0.30638	89.5	0.030	0.236E-05	0.236E-06
0.30724	98.3	0.082	0.179E-04	0.179E-05
0.30913	92.6	0.043	0.483E-05	0.483E-06
0.31233	95.9	0.062	0.103E-04	0.103E-05
0.31596	93.5	0.047	0.594E-05	0.594E-06
0.31972	98.5	0.084	0.188E-04	0.188E-05
0.32319	96.8	0.069	0.127E-04	0.127E-05
0.32643	96.7	0.068	0.124E-04	0.124E-05
0.32936	86.3	0.021	0.113E-05	0.113E-06
0.33189	93.0	0.045	0.529E-05	0.529E-06
0.33445	95.5	0.060	0.941E-05	0.941E-06
0.33709	90.5	0.033	0.298E-05	0.298E-06
0.33977	87.2	0.023	0.139E-05	0.139E-06
0.34271	94.5	0.053	0.748E-05	0.748E-06

0.34562	96.8	0.069	0.127E-04	0.127E-05
0.34850	94.6	0.054	0.765E-05	0.765E-06
0.35079	94.4	0.052	0.731E-05	0.731E-06
0.35270	98.8	0.087	0.201E-04	0.201E-05
0.35464	87.4	0.023	0.146E-05	0.146E-06
0.35661	87.1	0.023	0.136E-05	0.136E-06

0.35837	91.9	0.039	0.411E-05	0.411E-06
0.36045	92.6	0.043	0.483E-05	0.483E-06
0.36298	86.8	0.022	0.127E-05	0.127E-06
0.36603	92.7	0.043	0.494E-05	0.494E-06
0.36960	86.3	0.021	0.113E-05	0.113E-06
0.37328	98.5	0.084	0.188E-04	0.188E-05
0.37728	90.8	0.035	0.319E-05	0.319E-06
0.38078	80.6	0.011	0.305E-06	0.305E-07
0.38348	99.1	0.090	0.216E-04	0.216E-05
0.38537	90.7	0.034	0.312E-05	0.312E-06
0.38774	88.2	0.026	0.175E-05	0.175E-06
0.39055	91.4	0.037	0.366E-05	0.366E-06

```
MAIN    = 001B6E
4051F8 BYTES USED
EXECUTION BEGINS
ELECTRIC FIELD STRENGTH VS POSITION
[illegible]TION: CKOI.VF      ARRAY POSITION: 19
F[illegible] UENCY (KHZ):  96900.00    WAVELENGTH (M):0.310E+01
STREET:  BIOLOGY ROAD
INTERSECTING STREET:  PENFIELDGATE
   226 DATA POINTS WERE READ


     NUMBER OF DATA POINTS:      226


     MEAN FIELD STRENGTH (DBUV/M):     104.72


     STANDARD DEVIATION (DB):    102.454
STOP          0
*End
*Go
```

DOC.PLOT

Having created individual data files by executing BOB.MAIN several times, X-Y plotting and simple statistical processing was carried out. The plotting software developed (called DOC.PLOT) made use of plotting subroutines avilable under MUSIC, including automatic scale setting for both axes. For this reason, the choice of amplitude scales displayed on the graphs varies with the field strength data. This means that for a given street (with identical horizontal scales) the amplitudes of the field strength data are not directly comparable, however, the data are always conveniently displayed within the limits set by the automatic scale function. This type of scaling allows a convenient means of studying the structural form (morphology) of the data as opposed to providing a means for direct numerical comparison. If however the plots for two or more stations, on the same scale, are requested for comparison purposes, this type of output is also available.

A sample output of typical XY plots obtained for an AM, FM, and TV station is given in Section (5.4).

DOC.STAT

The fourth principle software developed, called DOC.STAT, provides elementary statistics of the data. This allows direct numerical comparison of the data for all stations along a given street using the mean and standard deviation. The DOC.STAT program was written in FORTRAN similar to BOB.MAIN and DOC.PLOT. The program reads the data stored in the files created by BOB.MAIN, then computes the mean and standard deviation (s.d.). The statistics generated were then used in identifying the major strongest stations of all the AM/FM/TV broadcast stations, as shown in tables (5.4.1) and (5.4.2).

It should be noted that DOC.STAT was used in processing the data for both the outdoor and indoor measurements. READ.DOC4, BOB.MAIN and DOC.PLOT were used in processing only the outdoor data, which comprises many times more measurements than the indoor data.

(.3) Level of Computational Effort and Magnitude of Data Bank.

This section will include a discussion of of the memory requirements and the amount of computing effort required in the running of the data proceesing software described earlier.

For the CPU time parameter, most individual CPU times require in the order of two to five seconds average and a maximum of fifteen seconds for the READ.DOC4 program. These requirements do not pose difficulties for the MUSIC system, thus the codes will continue to be used as they are. The running of the codes can further be optimized by creating load modules. This procedure should reduce execution times quite significantly and hence will further reduce the cost of each individual running of the BOB.MAIN, DOC.PLOT, and DOC.STAT programs as the data changes according to the choice of stations and routes selected for processing.

The size of the data bank for the outdoor survey of all routes around the periphery of the McGill campus and the university precinct occupies approximately 468K of memory, as shown in Table (4.3.1) below. On the MUSIC system, the maximum space allowed for a single disk file under the present research code is 4 000K, with 10 000K being the total maximum space assigned to a single code. Hence under the present circumstances it would appear that the computing resources presently available are adequate to carry out the intended data processing. However, it has been the experience of the present study that storage problems are encountered when the file size exceeds about 400K with records being lost at the end of the file. This problem can be remedied by splitting the single file into smaller files of manageable size. Since the magnitude of the measured data bank is larger than 400K, care has to be taken to manage the data to avoid losing parts of it especially when saving the data on a single MUSIC save file.

Shown below in Table (4.3.1) are typical memory requirements for the files containing the raw data as obtained from tape, the processed data, and the principle and other data processing programs developed at McGill, as described earlier.

Table (4.3.1). Typical Memory Requirements for Data Storage and Data Processing Software.

FILENAME	SYSTEM	RECORD SIZE	MEMORY SIZE	%USED	NOTE
Files Containing Raw Data:					
MCGILL.AFT	MUSIC "A"	128 LRECL	468K	99%	
MCGILL.UHF	MUSIC "A"	128 LRECL	296K	99%	
LABEL1.DOC	MUSIC "A"	128 LRECL	60K	98%	
Files Containing Data Processing Software:					
DUMPTAPE.ASCII	MVS/OS	80 LRECL	2K	33%	
DUMPTAPE.EBSIDIC	MVS/OS	80 LRECL	2K	33%	
FILE.TOTAPE128	MVS/OS	80 LRECL	2K	33%	
FILE.TOTAPE80	MVS/OS	80 LRECL	2K	33%	
READ.DOC4	MVS/OS	80 LRECL	2K	33%	1.
READ.DOC5	MVS/OS	80 LRECL	2K	66%	1.
BOB.MAIN	MUSIC "A"	80 LRECL	8K	100%	
DOC.STAT	MUSIC "A"	80 LRECL	4K	57%	
DOC.PLOT	MUSIC "A"	80 LRECL	4K	85%	1.
FLOOR.PLOT	MUSIC "A"	80 LRECL	2K	66%	1.
Typical Files Containing Processed Data:					
OUTDOOR (Maximum and typical length streets)					
CITE.HF	MUSIC "A"	80 LRECL	68K (max)	97%	
CITE.HF	MUSIC "A"	80 LRECL	14K (typ)	88%	
INDOOR (Typical for each floor)					
FLOOR0.DAT	MUSIC "A"	80 LRECL	2K	33%	
.	"	"	"	"	
.					
.					
FLOOR7.DAT	"	"	"	"	

Notes: 1. These programs require mainframe computer operator intervention for their execution.

(V). THE OUDOOR EM FIELD SURVEY

(.1) Overview of the Mobile Outdoor Survey Equipment.

In the present study of the Measurement, Analysis, and Forecasting of the EM Field Environment, the CRC mobile field scanning and recording unit, developed at the CRC laboratories, was the principal means of collecting large amounts of fieldstrength versus position data across a set of preselected frequencies. This vehicle was designed precisely for carrying out rapid grade level surveys of the EM environment over a citywide region. The mobile unit is equipped with a variety of sophisticated on-board equipment in addition to its rooftop aerials which are chosen to respond to the desired frequency bands.

The on-board facilties include a range of scanning receivers appropriately programmed for the chosen frequency ranges, as well as a minicomputer-based data acquisition and storage system integrated with the antenna and scanning receivers to form a complete mobile data gathering and storage facility. The measured data is immediately stored on magnetic tape. The tape can then be transferred to an off-board computer system for data processing and analysis. The outdoor data was transferred to McGill University in precisely the above manner for the management, processing, and analysis of the field strength versus position data along the chosen survey routes around the McGill Campus and the University precinct.

(.2) Description of Survey Routes.

In March 1983 numerous street level outdoor field strength measurements were recorded by the CRC Mobile frequency scanning and recording unit along several streets in downtown Montreal. The field strength data collected by the mobile recording unit was chosen to correspond to those streets forming the periphery of the McGill University campus located in downtown Montreal.

A map of the streets surveyed by the mobile unit, first for the AM/FM/TV except Channel 17, and later for UHF-TV Channel 17, is presented in Figures (5.2.1) and (5.2.2) respectively.

Fig. (5.2.1). Survey Route of the Mobile Field Recording Unit For the AM/FM/TV Survey Around the Downtown McGill Campus.

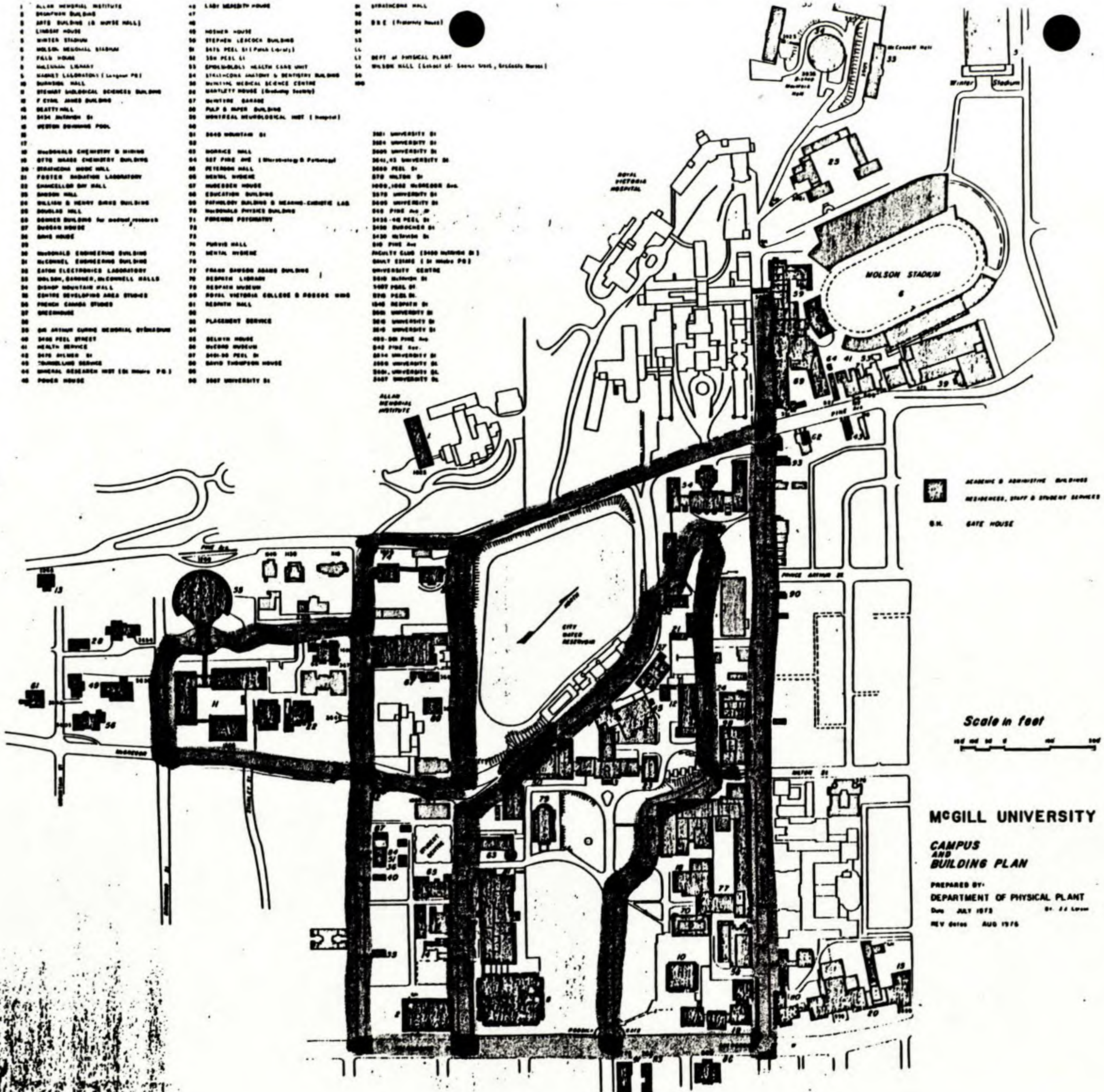

MOLSON STADIUM
Winter Stadium
ROYAL VICTORIA HOSPITAL
ALLAN MEMORIAL INSTITUTE
CITY WATER RESERVOIR
PINE Ave
ACADEMIC & ADMINISTRATIVE BUILDINGS
RESIDENCES, STAFF & STUDENT SERVICES
G.H. GATE HOUSE
Scale in feet
McGILL UNIVERSITY
CAMPUS AND BUILDING PLAN
PREPARED BY:
DEPARTMENT OF PHYSICAL PLANT
Date JULY 1973
REV dates AUG 1976

Fig. (5.2.2). Survey Route of the Mobile Unit for the UHF-TV Channel 17 Survey Around the Downtown McGill Campus.

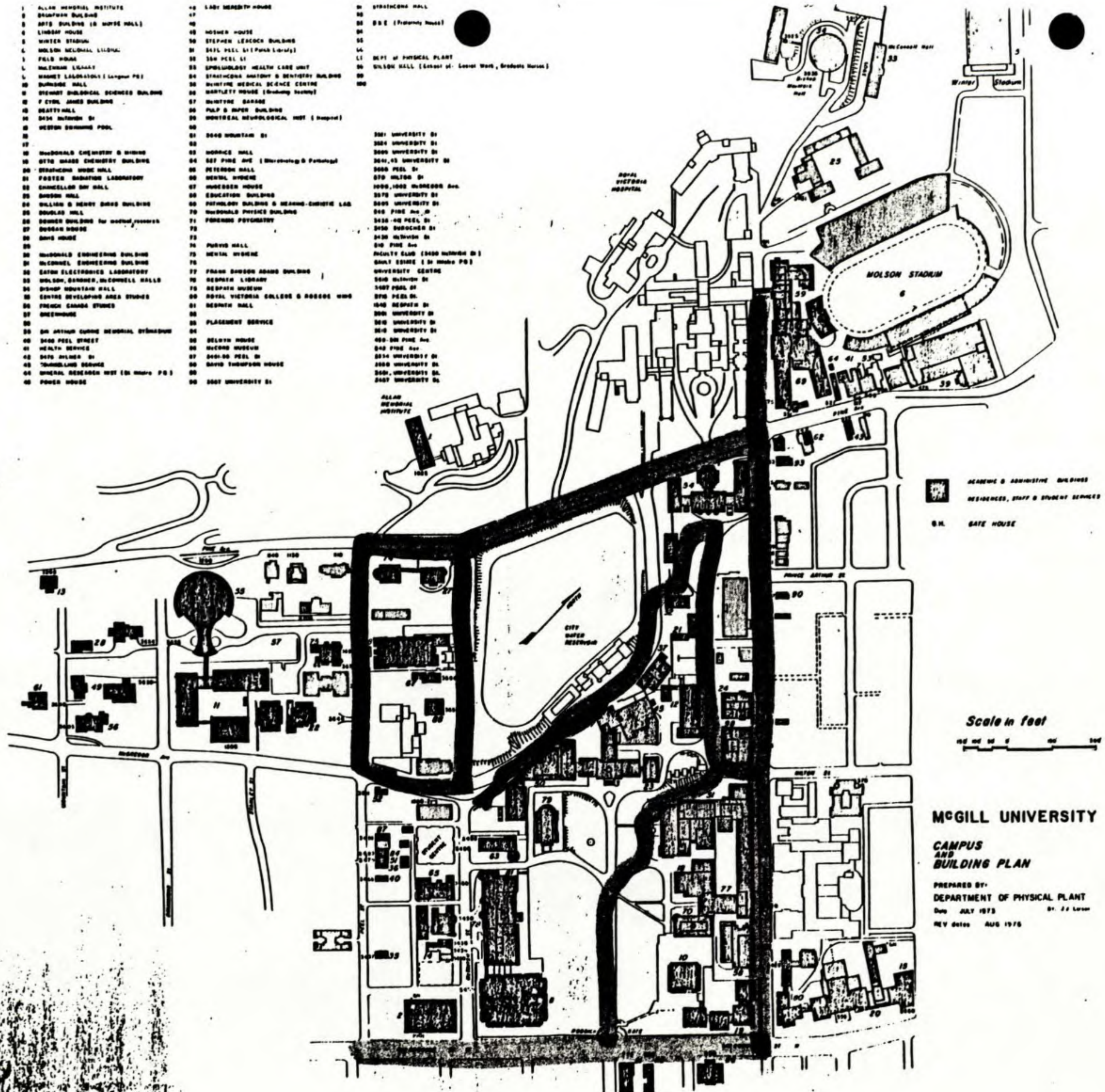

ROYAL VICTORIA HOSPITAL
ALLAN MEMORIAL INSTITUTE
MOLSON STADIUM
Winter Stadium
CITY WATER RESERVOIR
GATE HOUSE
Scale in feet
McGILL UNIVERSITY
CAMPUS AND BUILDING PLAN
PREPARED BY:
DEPARTMENT OF PHYSICAL PLANT
Date JULY 1973
REV dates AUG 1976

Table (5.2.1) presents the streets surveyed by the mobile field recording unit for all major AM, FM, and TV stations in the Montreal area, except for station CIVM (489.25 MHz), which represents channel 17 on the UHF-TV band. A separate survey at this frequency was made around the McGill campus at few days after the first McGill campus survey was made. Table (5.2.2) presents the survey route for the channel 17 survey.

Table (5.2.1). Streets Surveyed by Mobile Unit at all Montreal AM/FM/TV Broadcast Frequencies (except UHF-TV channel 17).

Route Number	STREET/INTERSECTING STREET (STARTING LOCATION)	STREET/INTERSECTING STREET (ENDING LOCATION)
1	University/Sherbrooke	Pine/University
2	Pine/University	Peel/Pine
3	Peel/Pine	McIntyre/Peel
4	McIntyre/Peel	Drummond/McIntyre
5	Drummond/McIntyre	Penfield/Drummond
6	Penfield/Drummond	Peel/Penfield
7	Peel/Penfield	Sherbrooke/Peel
8	Sherbrooke/Peel	Sherbrooke/University
9	McTavish/Penfield	Pine/McTavish
10	Pine/McTavish	Peel/Pine
11	Peel/Pine	Penfield/Peel
12	Penfield/Peel	Penfield/McTavish
13	Biology Road/Milton	Sherbrooke/Biology
14	Sherbrooke/Biology	McTavish/Sherbrooke
15	McTavish/Sherbrooke	Penfield/McTavish
16	Penfield/McTavish	Biology Road/Penfieldgate
17	Biology Road/Penfieldgate	Biology Road/Milton
18	University/Pine	University/Northend
19	Pine/Peel	Pine/Redpath

Table (5.2.2). List of Streets Surveyed for Channel 17 Meaurements.

Route Number	STREET/INTERSECTING STREET (STARTING LOCATION)	STREET/INTERSECTING STREET (ENDING LOCATION)
1A	University/Sherbrooke	Pine/University
2A	Pine/University	Peel/Pine
3A	Drummond/Peel	Penfield/Drummond
4A	Penfield/Drummond	Peel/Penfield
5A	Sherbrooke/Peel	Sherbrooke/University
6A	McTavish/Penfield	Pine/McTavish
7A	Pine/McTavish	Peel/Pine
8A	Peel/Pine	Penfield/Peel
9A	Penfield/Peel	Penfield/McTavish
10A	Biology Road/Milton	Sherbrooke/Biology
11A	Sherbrooke/Biology	McTavish/Sherbrooke
12A	Penfield/McTavish	Biology Road/Penfieldgate
13A	Biology Road/Penfieldgate	Biology Road/Milton
14A	University/Pine	University/Northend
15A	Pine/Peel	Pine/Redpath

(.3) Description of Data Obtained from Outdoor Survey.

The measured data stored on tape was transferred to the McGill system for subsequent data processing, plotting and analysis. In this connection, software was developed for the purpose of reading, processing, and plotting the data recorded by the mobile unit as described in section (4.2). Most of the data processing software was written in the FORTRAN language and compiled by the FORTRAN IV G compiler as supported by the MUSIC system. The principle programs (BOB.MAIN, DOC.PLOT, DOC.STAT) are fully operational on the MUSIC system at the present time.

In order to extract the field versus position data for all AM, FM, and TV stations along a given street, the BOB.MAIN program was run interactively many times. It should be noted that the program had to be modified several times in order to achieve as much interaction with the user as possible without giving too much concern to efficiency at this stage. However, in order to improve efficiency, load modules will be created and run using a linking loader available under MUSIC. This should increase execution speed by about three to four times. The BOB.MAIN program must be executed before DOC.PLOT or DOC.STAT since the latter programs involve the use of the data files created by BOB.MAIN. Data files can be created as long as the user provides the expected input data during program execution.

Besides the interactive input provided by the user, the BOB.MAIN program requires an input file containing the outdoor measurement data. The transfer of data from tape to disk is accomplished by running a program invoking the use of standard IBM Tape Utility Programs. Two such programs, READ.DOC4 and READ.DOC5, had to be developed for this purpose. Both programs were run under the OS/Batch system and therefore had to be written in Job Control Language (JCL). The resulting files containing the ASCII tape data were transferred to the MUSIC system and were stored under the filenames MCGILL.AFT and MCGILL.UHF, the former containing the AM/FM/TV measurements, the latter containing the Channel 17 measurements.

After creating data files containing the measurement data for a particular station and route using BOB.MAIN, the data was plotted and statistically analyzed using DOC.PLOT and DOC.STAT respectively. A sample output of typical outdoor data is given in in Figures (5.4.1) to (5.4.4) for one AM, two FM, and one TV station respectively. Elementary statistics (mean and standard deviation) were generated for all stations along a single route to compare the mean field strengths and to identify the four strongest stations, as shown in tables (5.4.1) and (5.4.2).

The following tasks can now be performed using the programs described below (program listings are given in Appendix A):

SOFTWARE TASK	MUSIC SAVE FILE
-- read data from tape into MUSIC save file;	READ.DOC4, READ.DOC5
-- tapedump of an ASCII tape;	DUMPTAPE.ASCII
-- create a MUSIC save file containing field strength versus position data for a particular street and station;	BOB.MAIN
-- plot the data stored in file created by BOB.MAIN;	DOC.PLOT
-- compute mean and standard deviation of data;	DOC.STAT

The data that was actually plotted is tabulated for selected streets and stations in table (5.3.1). In total, approximately 300 x-y type plots of field strength versus position along street of travel were produced. These are available as an atlas in the research project files, but because of the magnitude of the atlas only samples are given in figures (5.4.1) - (5.4.4) of this report.

The vertical axes indicating field intensity have been scaled to allow convenient dislpays of the measured field amplitude along a particular street in units of dBuV/m, V/m, W/m**2, mW/cm**2. This provides quick conversion between field strengths and power levels and vice versa. The next section contains a sample of the type of results obtained using the plotting facilities at McGill University.

The choice of streets and stations that were plotted was made according to the following criteria:

(i) All stations were plotted on the routes closest to the McConnell Building on the McGill campus (#1,2,3,13).

This allows comparison of the field levels from all AM/FM/TV transmitters in the Montreal area and enables the selection of the strongest stations. The routes that were plotted for all stations are indicated in Table (5.3.1).

(ii) The strongest stations were found from the plots of selected survey routes as described above. In general, it was found that certain FM and TV transmitters consistently produce strong e.m. fields; these stations were therfore plotted for the survey routes as indicated in table (5.3.1). In general, the AM field levels were found to be several dB below the FM and TV field levels hence no further plotting and processing of AM data was carried out since our interest will be focused to the 'worst offenders'.

Table (5.3.1). Data Plotted for AM/FM/TV Outdoor Survey (sampling interval = 5 meters).

Route # STATION		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	CFCF.VA	*	*	*										*						
2	CBF.VA	*	*	*										*						
3	CKAC.VA	*	*	*										*						
4	CJAD.VA	*	*	*										*						
5	CKVL.VA	*	*	*										*						
6	CBM.VA	*	*	*										*						
7	CKGM.VA	*	*	*										*						
8	CHRS.VA	*	*	*										*						
9	CJMS.VA	*	*	*										*						
10	CFMB.VA	*	*	*										*						
11	CKO.VA	*	*	*										*						
12	CKLM.VA	*	*	*										*						
13	CBFT.VT	*	*	*										*						
14	CBMT.VT	*	*	*										*						
15	CFQR.VF	*	*	*										*						
16	CBM.VF	*	*	*										*						
17	CKMF.VF	*	*	*										*						
18	CJFM.VF	*	*	*										*						
19	CKOI.VF	*	*	*										*						
20	CHOM.VF	*	*	*										*						
21	CBF.VF	*		*										*						
22	CINQ.VF	*		*										*						
23	CFGL.VF	*		*										*						
24	CITE.VF	*		*										*						
25	CBFT.HT	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
26	CBMT.HT	*		*										*						
27	CFQR.HF	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
28	CBM.HF	*		*										*						
29	CKMF.HF	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
30	CJFM.HF	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
31	CKOI.HF	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
32	CHOM.HF	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
33	CBF.HF	*		*										*						
34	CINQ.HF	*		*										*						
35	CFGL.HF	*		*										*						
36	CITE.HF	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
37	CFTM.HT	*		*										*						
38	CFCF.HT	*		*										*						
39	CFTM.HT	*	*	*										*						
40	CFCF.VT	*	*	*										*						

Note: The station polarization (Horizontal(H),Vertical(V)) and modulation (AM-(A),FM-(F),TV-(T)) are indicated by the last two letters respectively of each station entry.

(.4) SAMPLE OUTPUT OF OUTDOOR DATA

Figure (5.4.1). Sample Output of Outdoor Data: AM Station

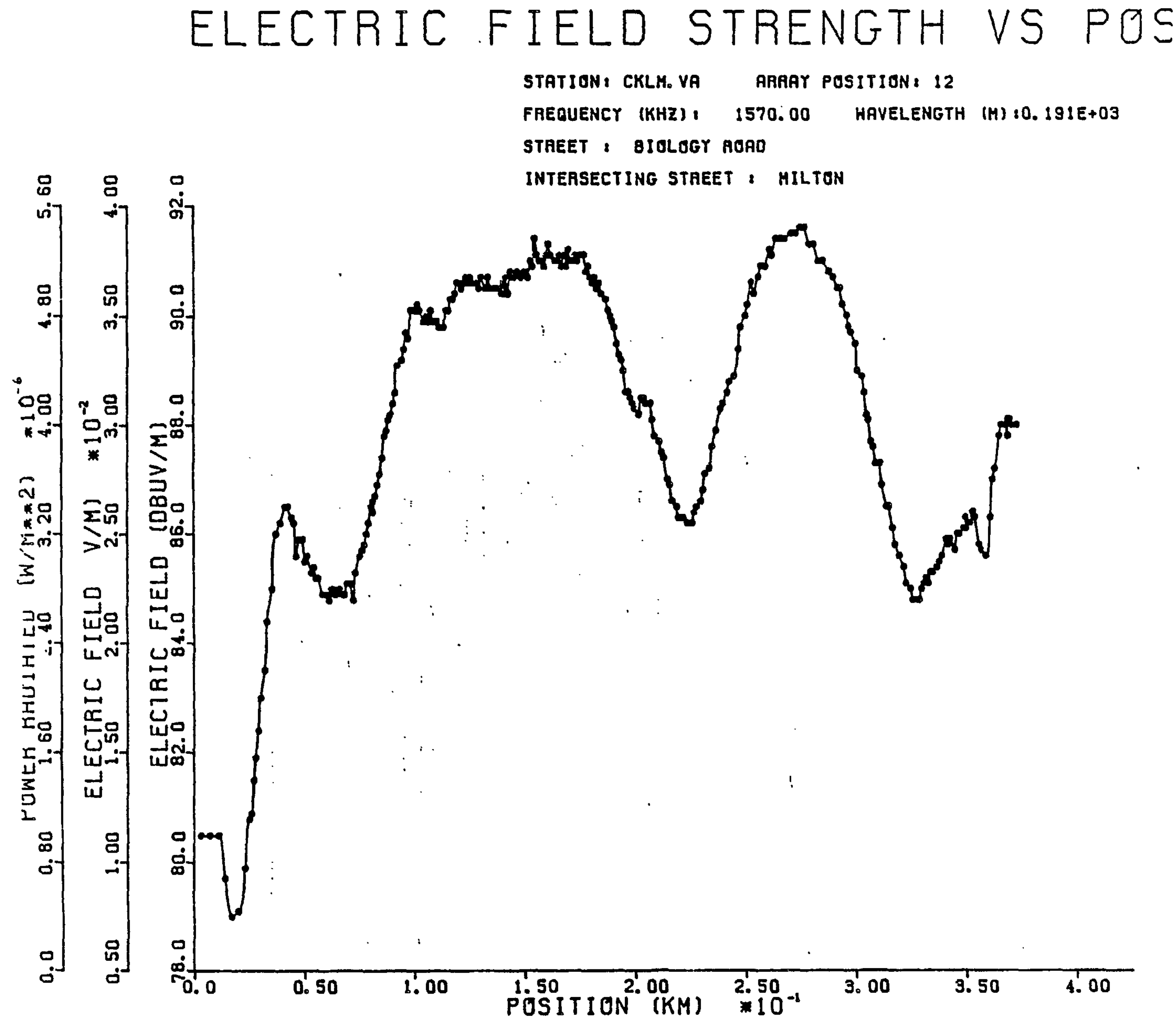


Figure (5.4.2). Sample Output of Outdoor Data: FM Station

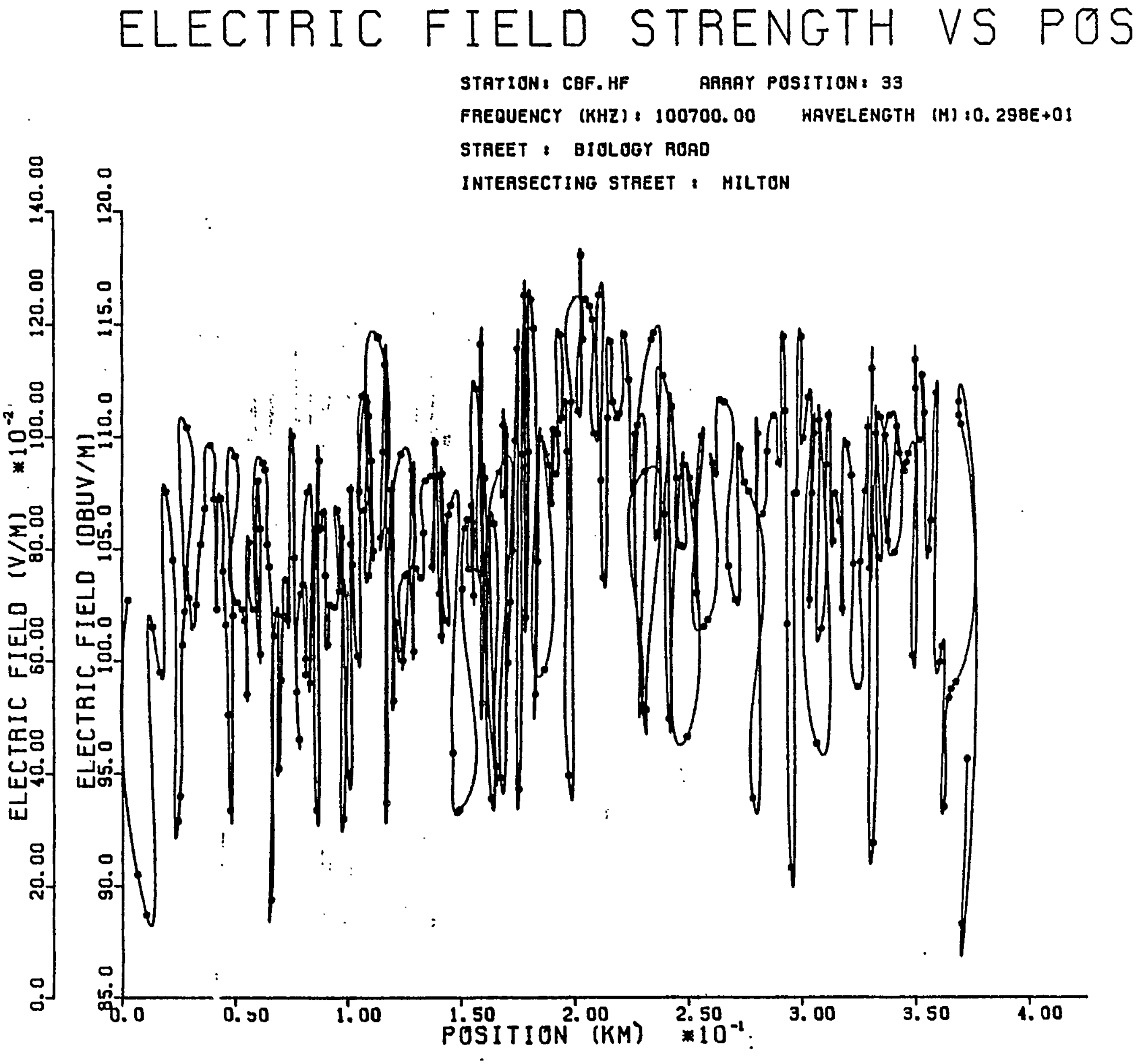


Figure (5.4.3). Sample Output of Outdoor Data: FM Station

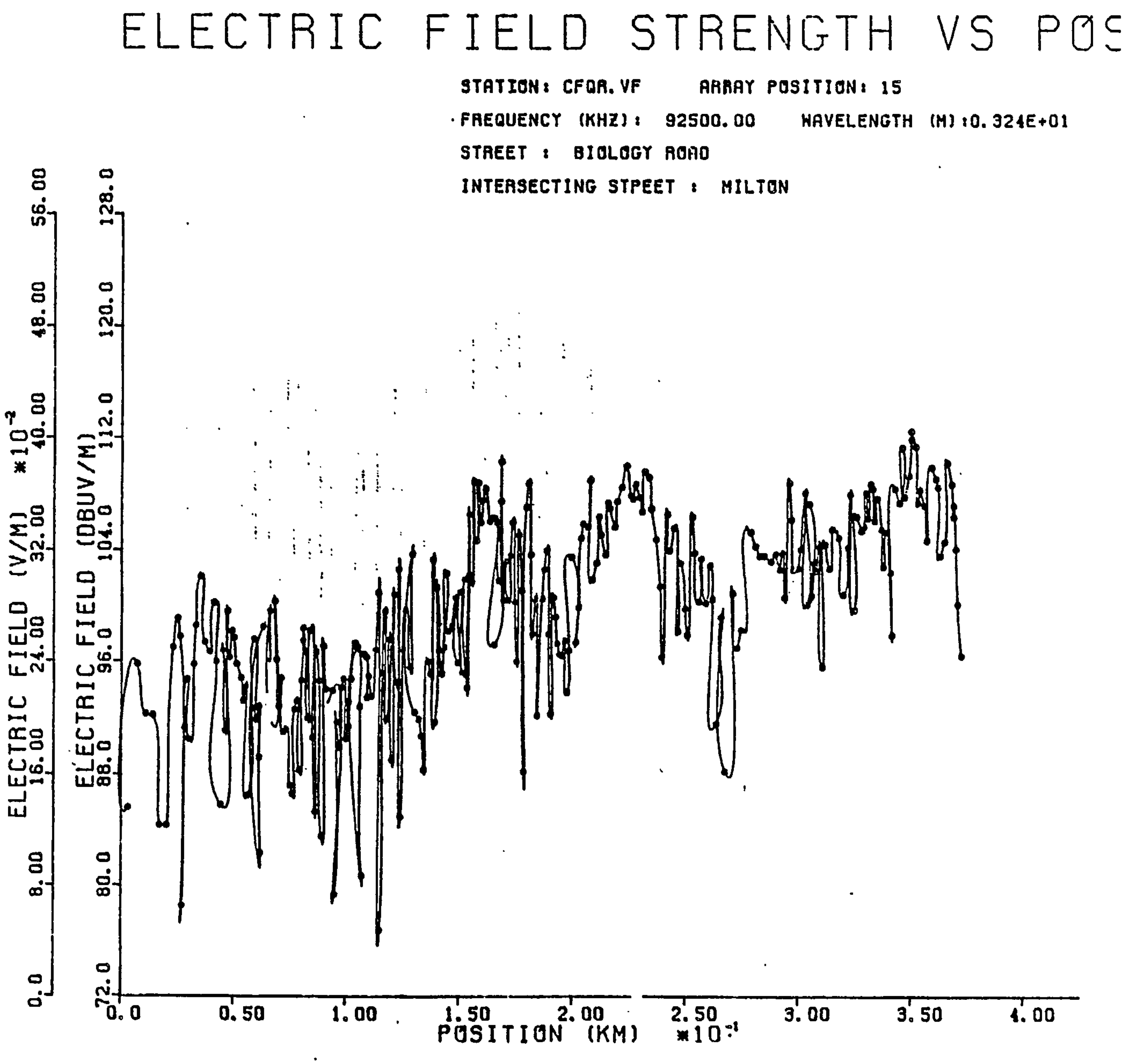
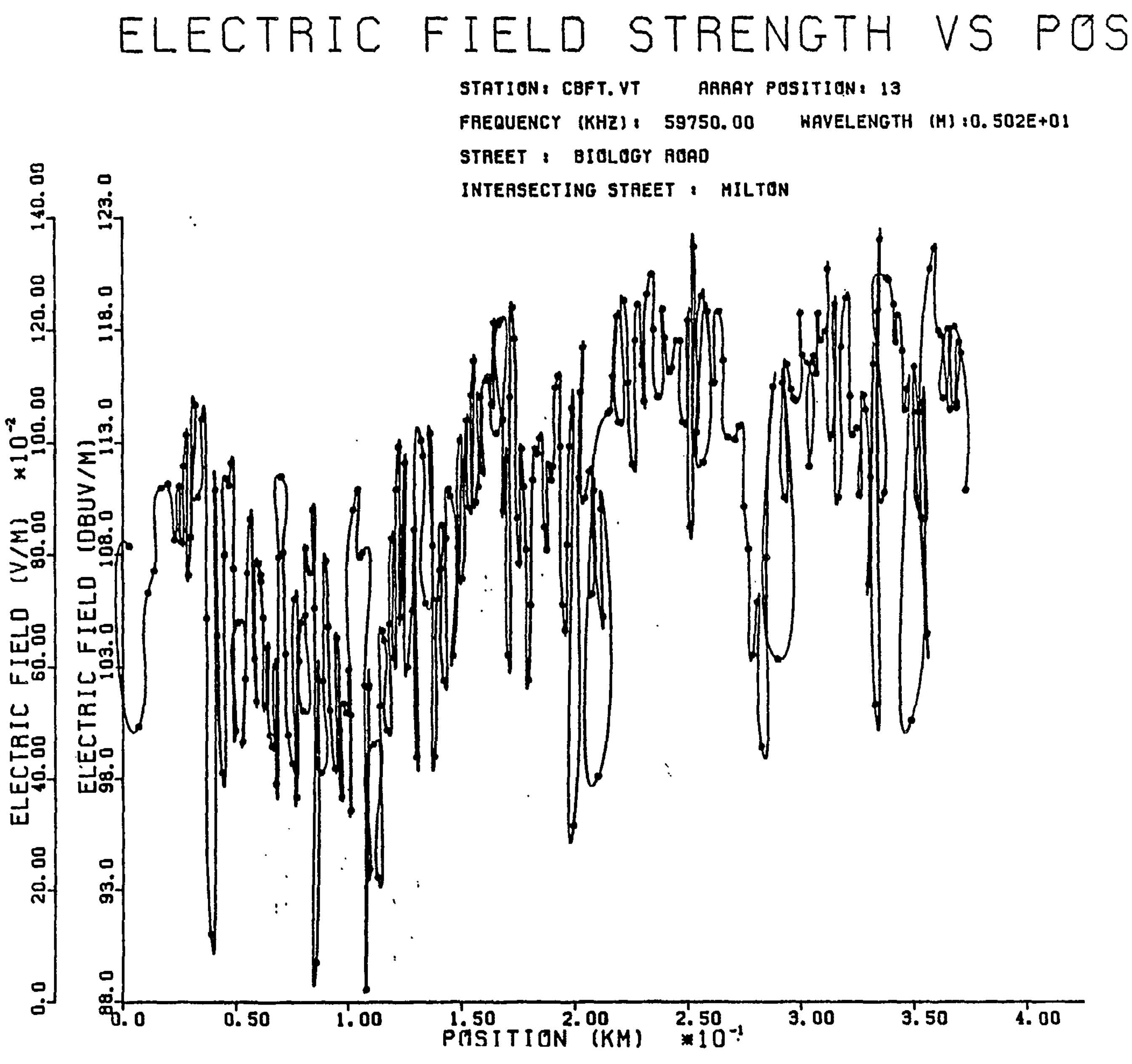


Figure (5.4.4). Sample Output of Outdoor Data: TV Station



(.5) Comparison of Measurements Against Free Space Values.

The outdoor field strength measurements provide a means of establishing a basis for the modelling of the outdoor em environment. A simple way to evaluate the usefulness of a particular model is to compare the results generated by the model with actual measurements. This comparison is carried out for the outdoor measurements pertaining to a selected street nearest to the McGill Campus. The data is averaged initially by graphical means and subsequently by statistical analysis using the data files containing data for each individual station. Using the above method, the mean field strengths for each station are compared to the free space values as given by table (3.3.1). This simple analysis is summarized below in Table (5.5.1) from which certain general observations will be made.

Table (5.5.1). Outdoor Field Levels Measured at Grade Level Near the McGill Campus Versus Free Space Levels.

STN	Frequency (kHz/MHz)	Location (route #)	Measured Values (dBuV/m) mean	s.d.	N	Free Space F.S. (dBuV/m)	Diff (dB)
AM TRANSMITTERS:							
CFCF	600 kHz	1	90.5	85.1	319	97.9	-7.4
CBF	690 kHz	1	98.2	93.8	319	106.6	-8.4
CKAC	730 kHz	1	87.8	82.4	319	99.5	-11.7
CJAD	800 kHz	1	85.4	79.1	319	101.0	-15.6
CKVL	850 kHz	1	86.2	80.7	319	103.9	-17.7
CBM	940 kHz	1	91.2	86.8	319	107.1	-15.9
CKGM	980 kHz	1	80.5	75.8	319	96.4	-15.9
CHRS	1090 kHz	1	76.3	70.5	319	89.9	-13.6
CJMS	1280 kHz	1	89.0	85.6	319	107.0	-18.0
CFMB	1410 kHz	1	83.4	79.2	319	101.0	-17.6
CKO	1470 kHz	1	73.5	71.4	319	96.5	-23.0
CKLM	1570 kHz	1	81.9	76.8	319	104.8	-22.9
FM TRANSMITTERS:							
CFQR	92.5 MHz	1	93.5	88.5	319	106.5	-13.0
CBM	93.5 MHz	1	85.4	76.3	319	103.4	-18.0
CKMF	94.3 MHz	1	93.3	88.3	319	106.5	-13.2
CJFM	95.9 MHz	1	92.5	87.5	319	106.5	-14.0
CKOI	96.9 MHz	1	102.2	100.0	319	121.7	-19.5
CHOM	97.7 MHz	1	90.8	85.6	319	106.5	-15.7
CBF	100.7 MHz	1	93.0	86.2	319	109.5	-16.5
CINQ	102.3 MHz	1	78.4	73.6	319	88.9	-10.5
CFGL	105.7 MHz	1	83.5	74.2	319	112.2	-28.7
CITE	107.3 MHz	1	100.9	97.4	319	121.9	-21.0
TV TRANSMITTERS:							
CBFT	59.75 MHz (A)	1	107.4	101.5	319	(A) 97.3 (A)	+10.1
CBFT	55.25 MHz (V)	1	117.4	--	--	(V) 107.3 (V)	+10.1
CBMT	87.75 MHz (A)	1	79.2	70.5	319	(A) 109.5 (A)	-30.3
CBMT	83.25 MHz (V)	1	87.4	--	--	(V) 117.7 (V)	-30.3
CFTM	197.75 MHz (A)	1	87.2	79.1	319	(A) 114.4 (A)	-27.2
CFTM	193.25 MHz (V)	1	90.3	--	--	(V) 117.5 (V)	-27.2
CFCF	209.75 MHz (A)	1	86.0	79.1	319	(A) 114.4 (A)	-28.4
CFCF	205.25 MHz (V)	1	89.1	--	--	(V) 117.5 (V)	-28.4
CIVM	493.75 MHz (A)	1	--	--	--	(A) 110.9 (A)	--
CIVM	489.25 MHz (V)	1	--	--	--	(V) 117.9 (V)	--

The route #1 as indicated in table (5.5.1) above corresponds to the street section between the corner of University and Sherbrooke and the corner of University and Pine as obtained from table (5.2.1). This particular route was chosen for comparing free space levels with measured grade level field strength data since it is near to the McConnell Engineering Building in which indoor measurements were made. It also provides a route directed towards towards Mount Royal on which the main FM/TV transmitting tower is stationed.

From the above comparison of outdoor grade level field levels, the following points of interest are detailed below:

AM STATIONS

In the case of the AM transmitters, it is evident from Table (5.5.1) that:

(a) the spread in the data as given by the standard deviation is very large, typically between 5 and 10 dB below the mean;

(b) the measured outdoor AM data are, on average, about 15 to 30 dB LESS than the free space levels, suggesting that other factors besides the direct wave (1/r) falloff will likely affect the wave propagation;

(c) the mean values, except for one AM station, i.e., CBF (690 kHz), are generally between 75 dBuV/m (0.0056 V/m), and 90 dBuV/m (0.0316 V/m). SEE APPENDIX "C" FOR DETAILS.

FM STATIONS

For the FM transmitters, the following points of interest are observed from table (5.5.1):

(a) as for the AM stations, the spread in the data is very large, again between 5 and 10 dB below the mean;

(b) the measured values are also consistently LOWER than the free space values by about 10 to 20 dB on average; hence the measured values are closer to the free space values than in the case for the AM stations. This suggests that the propagation of the direct wave (1/r) component in the FM band (88-108 MHz) band is not degraded as much as it is in the AM band (54-1580 kHz). This fact can be partly understood from table (3.3.1) where it is clear that the AM distances are about ten times greater than the FM distances;

(c) the mean values are generally between 85 and 105 dBuV/m (0.018 and 0.18 V/m).

TV STATIONS

The folowing observations are made of the TV transmitter data in table (5.5.1):

(a) the spread in the data is large, typically between 5 and 10 10 dB below the mean;

(b) the measured values are, on average, between 25 and 30 dB LESS than the free space values, suggesting a rather severe signal degradation in this band;

(c) the mean values range between 80 and 110 dBuV/m or 0.01 and 0.32 V/m.

Table (5.5.2) identifies the 4 strongest stations in the Montreal area and merit particular attention. These will be considered separately in the Discussion.

Table (5.5.2). Outdoor Field Strengths Measured at Grade Level at the McGill Campus for 4 Strongest Broadcast Stations.

Station	Frequency (MHz)	Route Number	Measured Value (dBuV/m) mean	s.d.	Free Space (dBuV/m) table(3.3.1)	Sample size N
University/Sherbrooke to Pine/University						
CBF.VA	.69	1	98.21	93.80	106.6	319
CKOI.VF	96.90	1	96.99	97.86	121.7	319
CITE.VF	107.30	1	97.62	100.23	121.9	319
CBFT.VT (A)	59.75	1	107.44	101.50	97.3	319
CBFT.VT (V)	55.25	1	117.44	--	107.3	-
Biology Road/Milton to Sherbrooke/Biology						
CBF.VA	.69	13	102.33	97.59	106.6	288
CKOI.VF	96.90	13	107.39	106.05	121.7	288
CITE.VF	107.30	13	102.81	98.63	121.9	288
CBFT.VT (A)	59.75	13	112.24	108.48	97.3	288
CBFT.VT (V)	55.25	13	122.24	--	107.3	--
Biology Road/Penfieldgate to University/Pine						
CBF.VA	.69	17	98.62	94.09	106.6	226
CKOI.VF	96.90	17	104.72	102.45	121.7	226
CITE.VF	107.30	17	105.75	104.23	121.9	226
CBFT.VT (A)	59.75	17	107.11	101.43	97.3	226
CBFT.VT (V)	55.25	17	117.11	--	107.3	--

Note: For television station CBFT, (A) refers to audio carrier, (V) refers to video carrier measurements.

(VI). INDOOR MEASUREMENTS

(.1) Methodology.

Indoor field strength measurements were carried out on several floors of the McConnell Engineering Building in August/September 1983. The measurements were made using a simple FM receiver with the automatic gain control disconnected, an rf probe, and a voltmeter. It should be noted that these measurements were of a preliminary exploratory nature and the instrumentation was therefore kept to a simple primitive minimum. The accuracy required was for determining the orders of magnitude in absolute terms and to indicate the approximate relative levels at different locations.

To avoid nonlinerarities in the IF voltage due to the Automatic Gain Control (AGC) feedback circuit of the receiver, the AGC was disconnected. The rf probe was used to measure the voltage at the output of the IF stage; this voltage is then directly proportional to the voltage induced in the dipole antenna when the receiver is not saturated. If the receiver happens to be saturated, the IF voltage will not increase when the antenna voltage increases thus rendering useless data. At one of the FM frequencies (i.e. 96.9 MHz) it was found that many data points, especially the maximum values, fell in the non-linear range of the IF voltage versus signal voltage transfer characteristic. This situation prompted the measurements to be repeated at a weaker FM station (i.e. 97.7 MHz). The data at this frequency was found to be in the linear range for almost 100% of the time versus about 50% of the time in the case of the 96.9 MHz data.

Preliminary indoor measurements were carried out at various locations on each floor of the same building. These data were plotted and are given in section (6.2) along with a floor plan of each floor of the McConnell Building showing the corresponding locations of each measurement.

The e.m. field values were computed, as described below, from the equivalent induced voltage. This induced voltage was obtained from the IF output using a calibration curve between the two latter voltages. The calibration curve indicates the linear range of the receiver, which ranges from 0-3 Volts.

For a thin half-wave dipole antenna (as assumed here), the field intensity is given by the following relation:

$$E = V/l \tag{6.1}$$

where:

V = voltage induced in the dipole antenna

l = effective length of the dipole.

The dipole antenna output and the receiver input requires a simple impedance match to provide maximum power transfer from the antenna to the receiver. This impedance matching can be achieved by using a balun transformer, as described in the Phase I report of the present study.

The effective length of a dipole antenna is given by,

$$l = (\lambda/\pi)*\tan(\pi L/2\lambda) \quad (6.2)$$

where L is the physical length of the dipole. For a thin half-wave dipole, $L = \lambda/2$ so that $l = \lambda/\pi$. Thus the field measured by the antenna is given by:

$$E = V\pi/\lambda \quad (6.3)$$

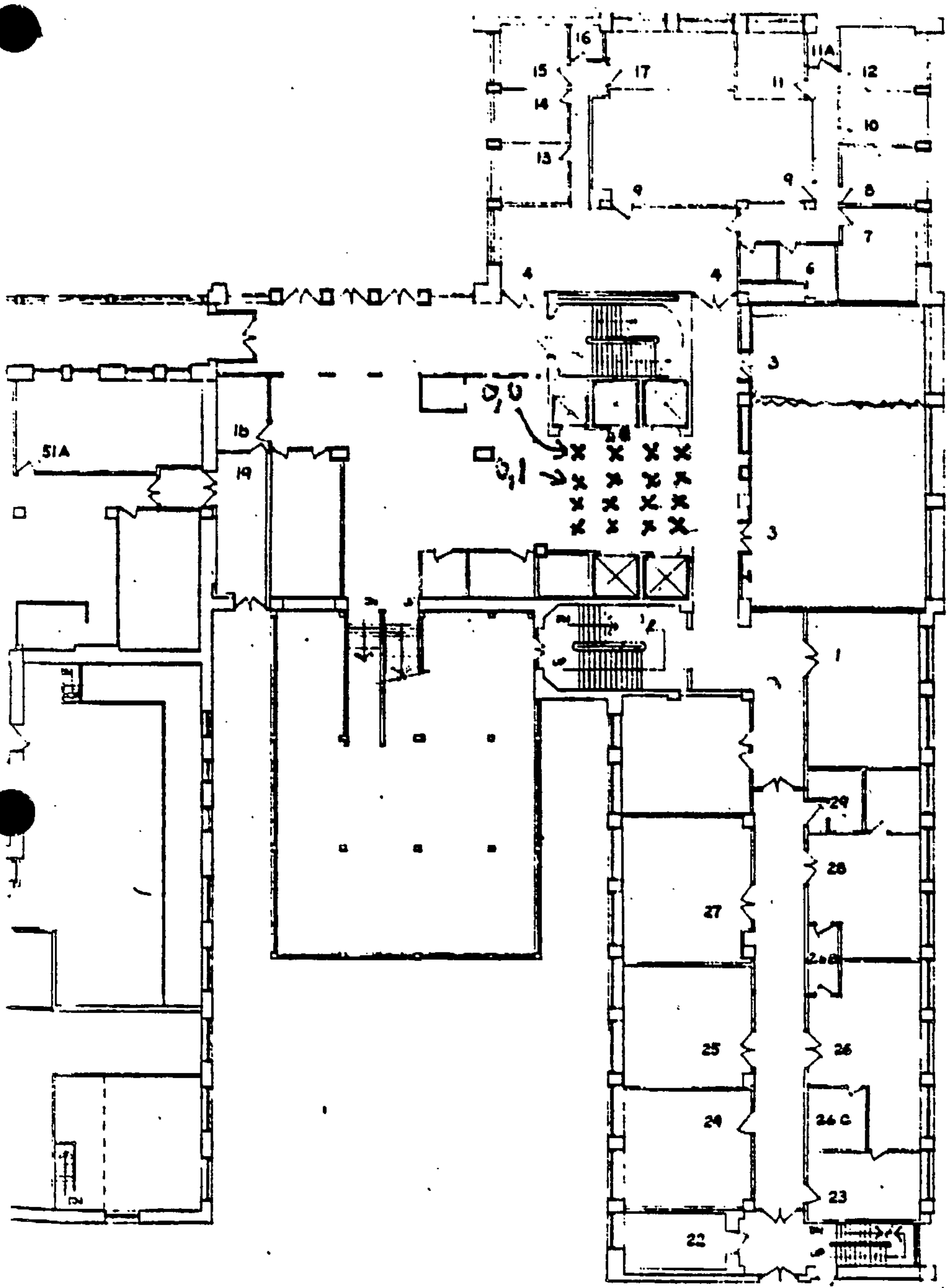
As mentioned, the voltage V induced in the dipole is obtained from a calibration curve. This calibration curve was obtained by feeding the output of a standard signal generator (HP8656A) into the receiver input and measuring the IF voltage output. An rf probe and a HINKI 105 FET probe tip were used to measure the voltage at the output of the IF stage.

A map of each floor of the McConnell building is presented in the following pages in order to locate the actual points of measurement within the McConnell Building. The reference point (0,0) is marked on each map; actual measurements were made with a portable field measurement unit at two FM frequencies, 96.9 MHz (CKOI) and later at 97.7 MHz (CHOM). The first set of measurements at 96.9 MHz had to be repeated at the 97.7 MHz frequency, a weaker station, in order to avoid saturating the receiver which was occuring at the 96.9 MHz (CKOI) frequency. (The receiver's dial calibration was "99" for the 97.7 MHz frequency as indicated on the plots).

The maps were obtained from the office of the Building Director of the Faculty of Engineering.

In the following section, the indoor measurements and a floor plan of each floor of the McConnell Building will be presented.

(.2) INDOOR MEASUREMENT DATA



REVISED:	FEBRUARY, 1979.	G. WHITELAW

GROUND FLOOR PLAN

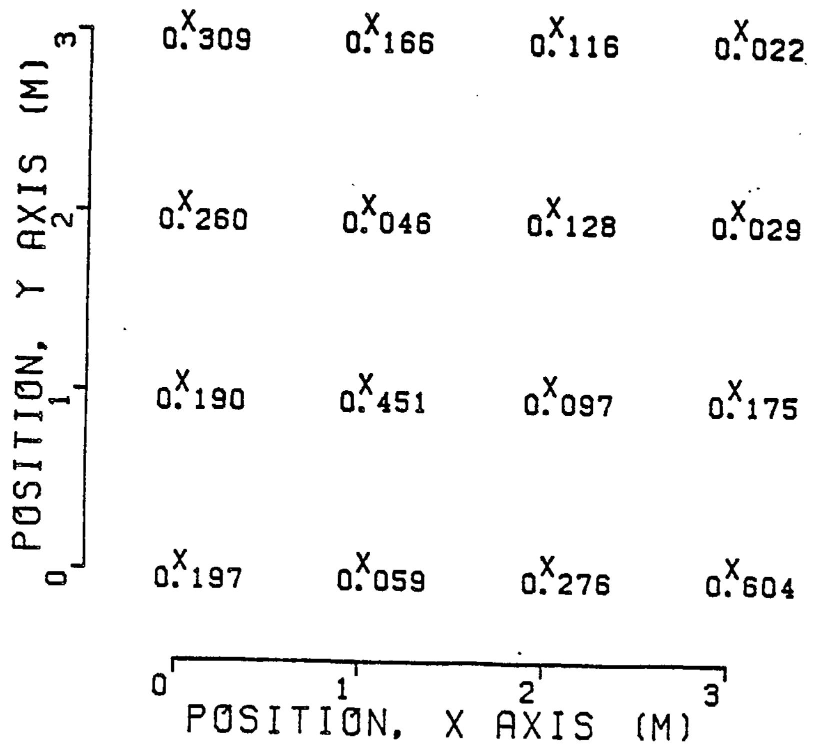
MacDonald & McConnell Engineering Bulds. McGILL

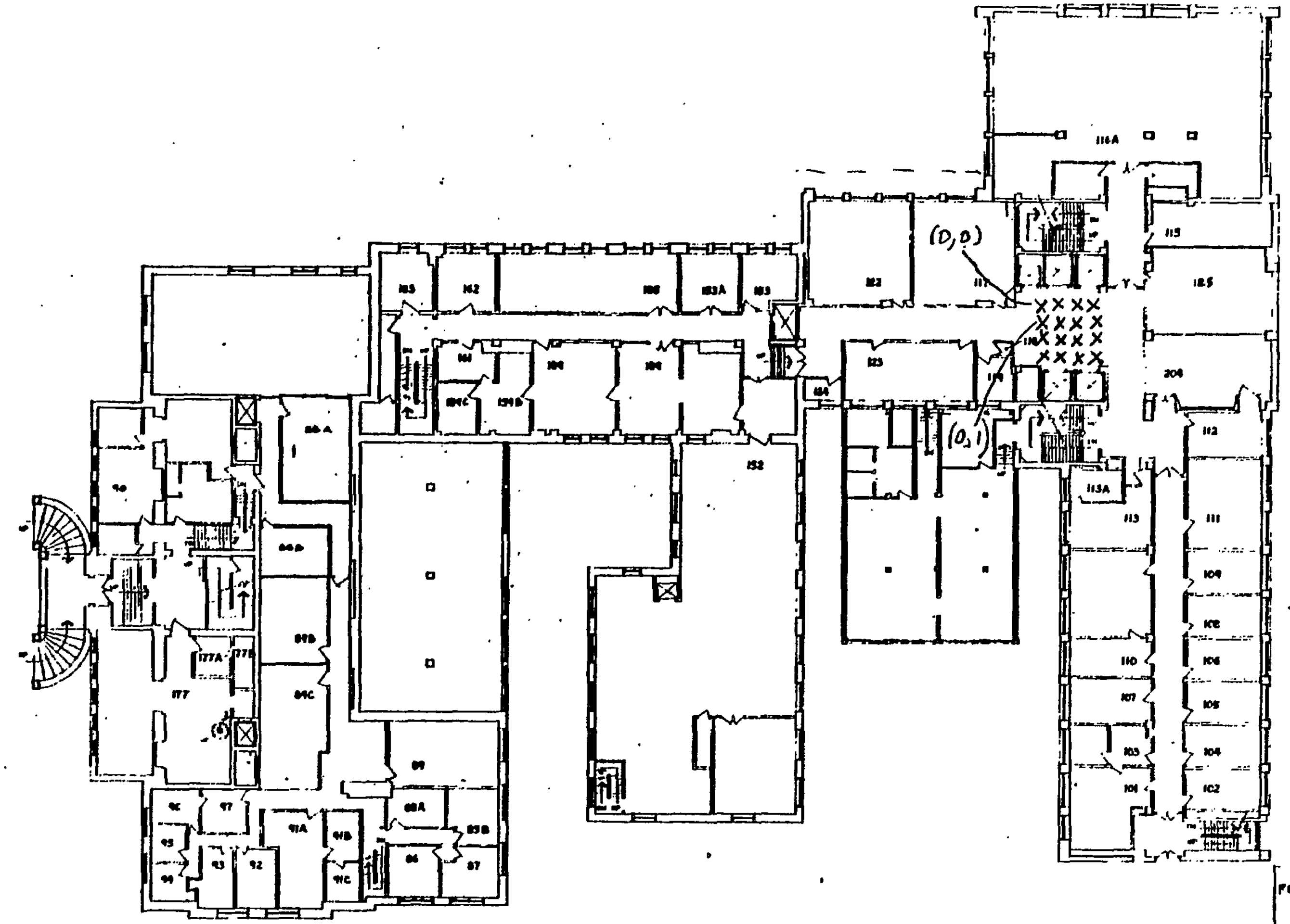
Drawn by	Patrick LELAND	
Checked		
Scale	1/16" = 1'-0" 1:192	Dwg # 2
Date	Jan-76	

INDOOR FIELD STRENGTH MEASUREMENTS

MCCONNELL ENGINEERING BUILDING
FREQUENCY: "99 MHZ" (Actually, 97.7 MHz)
LOCATION: GROUND FLOOR ELEVATOR

FIELD VALUES ARE IN V/M





REVISED	FEBRUARY, 1979.	G. WHITELAW

FIRST FLOOR PLAN

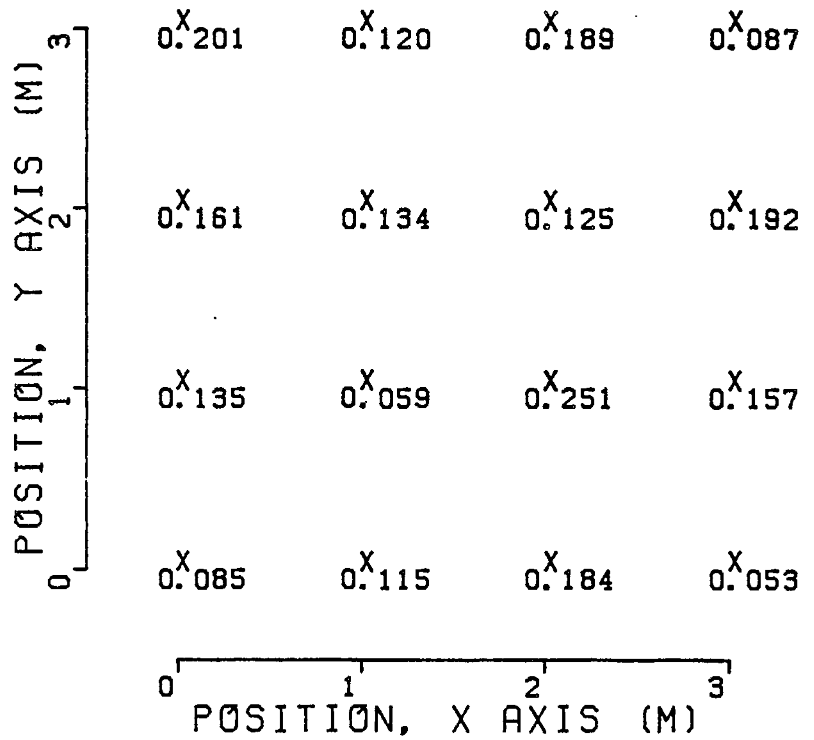
Macdonald & McConnell Engineering Bldgs, McGill

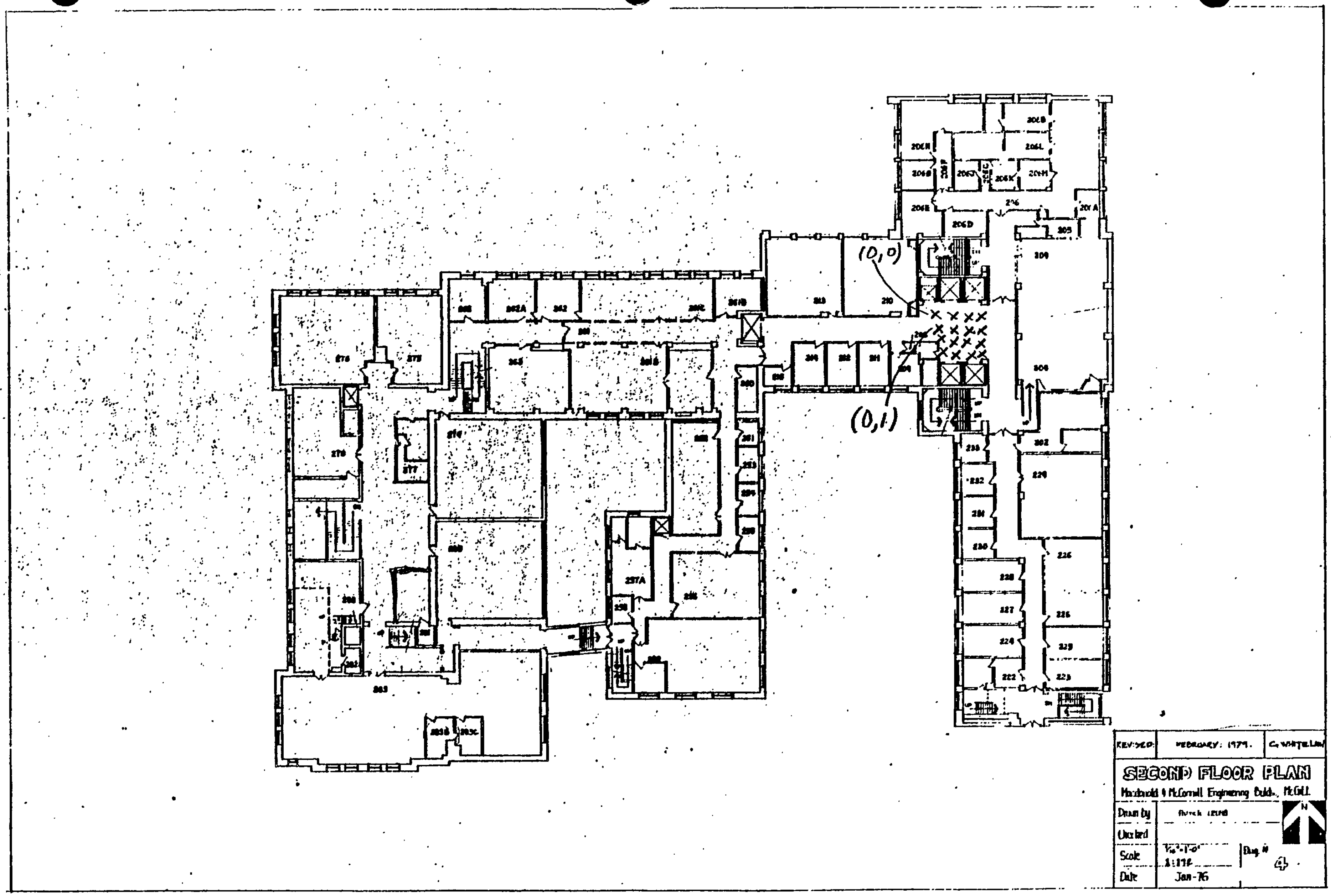
Drawn by			
Checked			
Scale	1/16" = 1'-0" 1:192	Dwg #	8
Date	Jun - 76		

INDOOR FIELD STRENGTH MEASUREMENTS

MCCONNELL ENGINEERING BUILDING
FREQUENCY: "99 MHZ"
LOCATION: 1ST FLOOR ELEVATOR

FIELD VALUES ARE IN V/M





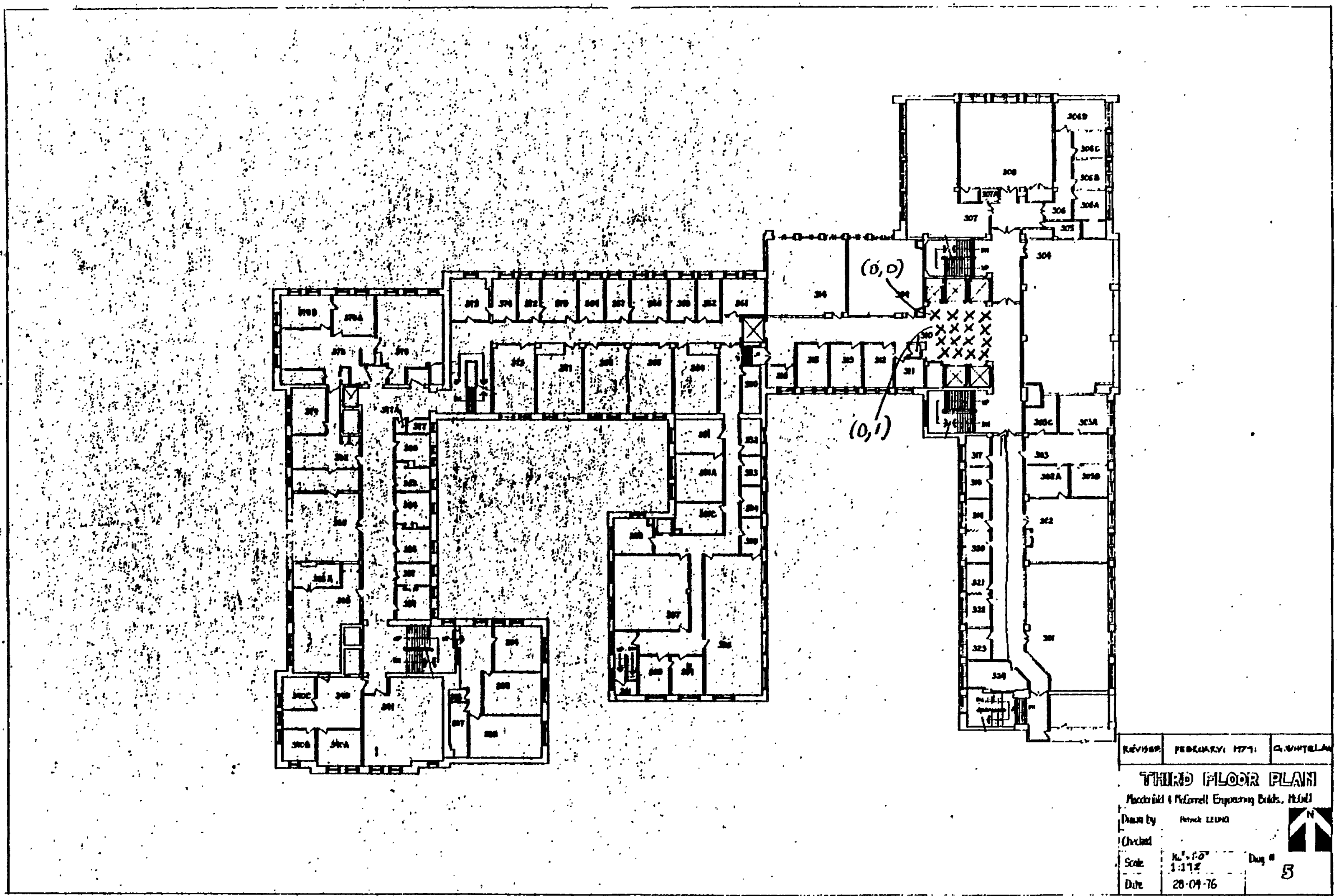
(0,0)
(0,1)
237A
SECOND FLOOR PLAN
Drawn by
Checked
Scale
1:176
Date
Jan-76
Dwg #
4
N

INDOOR FIELD STRENGTH MEASUREMENTS

MCCONNELL ENGINEERING BUILDING
FREQUENCY: "99 MHZ"
LOCATION: 2ND FLOOR ELEVATOR

FIELD VALUES ARE IN V/M

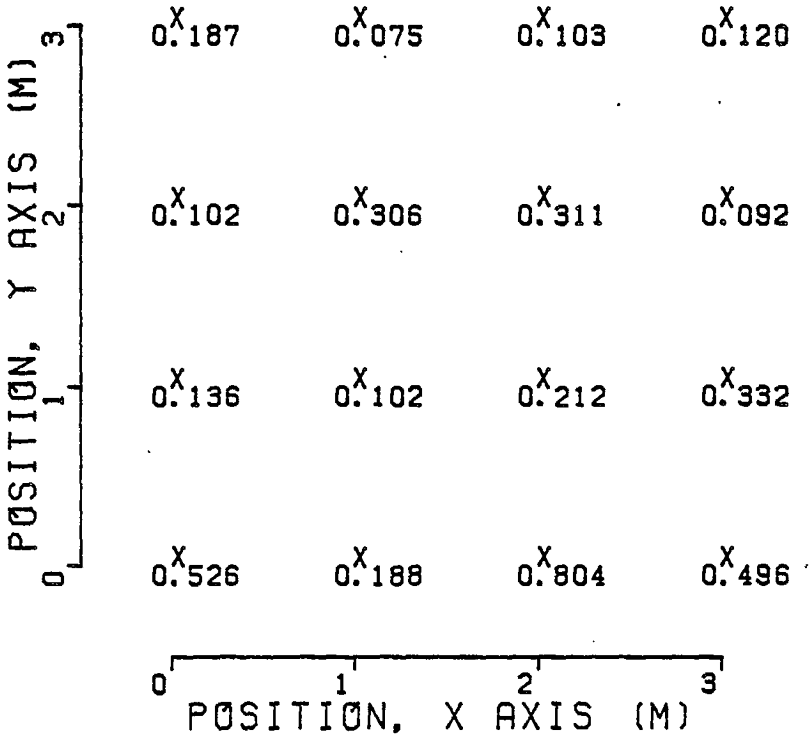
POSITION, Y AXIS (M) \ POSITION, X AXIS (M)	0	1	2	3
3	0.003	0.001	0.002	0.001
2	0.206	0.125	0.084	0.382
1	0.090	0.220	0.262	0.139
0	0.162	0.132	0.267	0.262

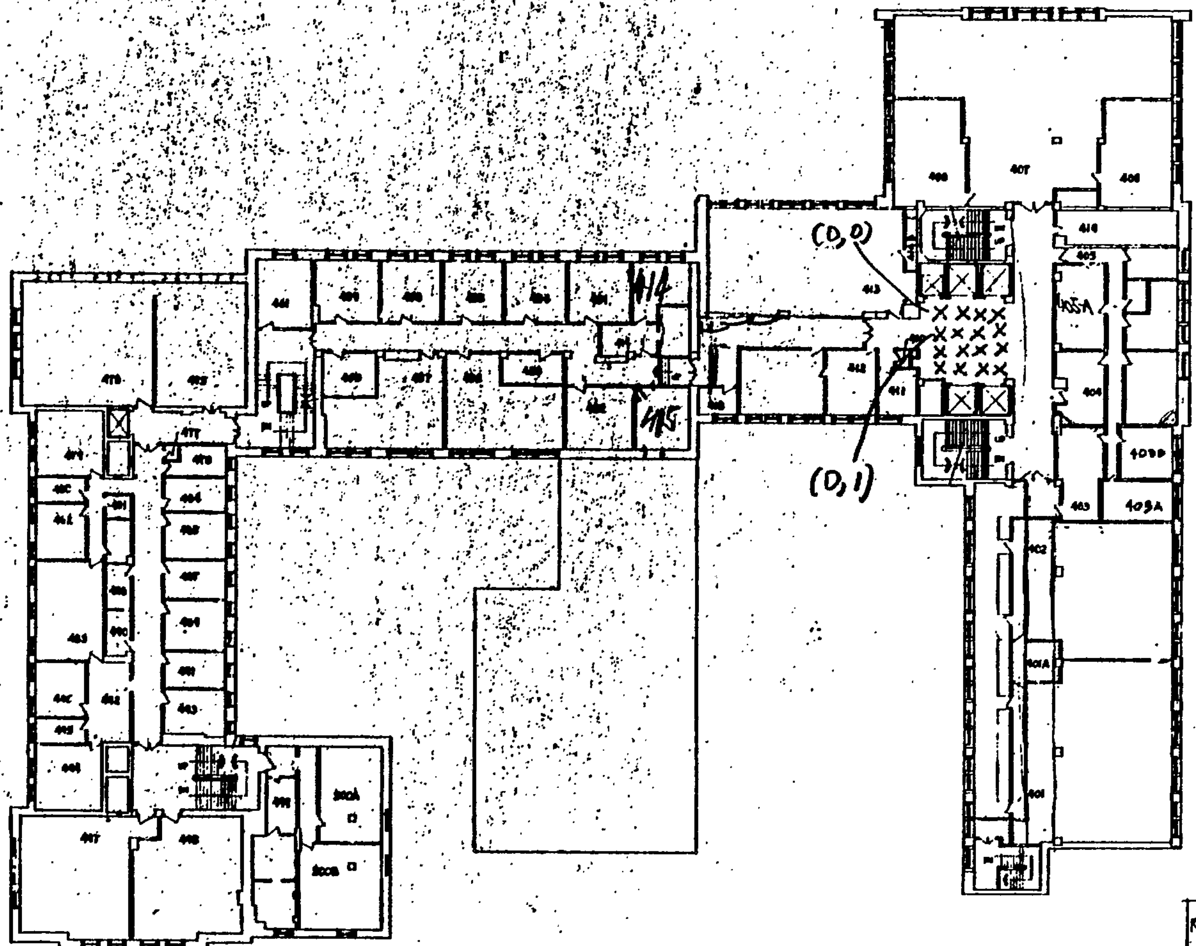

(0,0)
(0,1)
307
304
305
306
306A
306B
306C
306D
THIRD FLOOR PLAN
Drawn by
Checked
Scale
1:112
Date
28-04-76
Dwg #
5
N

INDOOR FIELD STRENGTH MEASUREMENTS

MCCONNELL ENGINEERING BUILDING
FREQUENCY: "99 MHZ"
LOCATION: 3RD FLOOR ELEVATOR

FIELD VALUES ARE IN V/M





REVISED	FEBRUARY : 1979	G.WHITELAW

FOURTH FLOOR PLAN

Macdonald & McConnell Engineering Bldgs. McGill

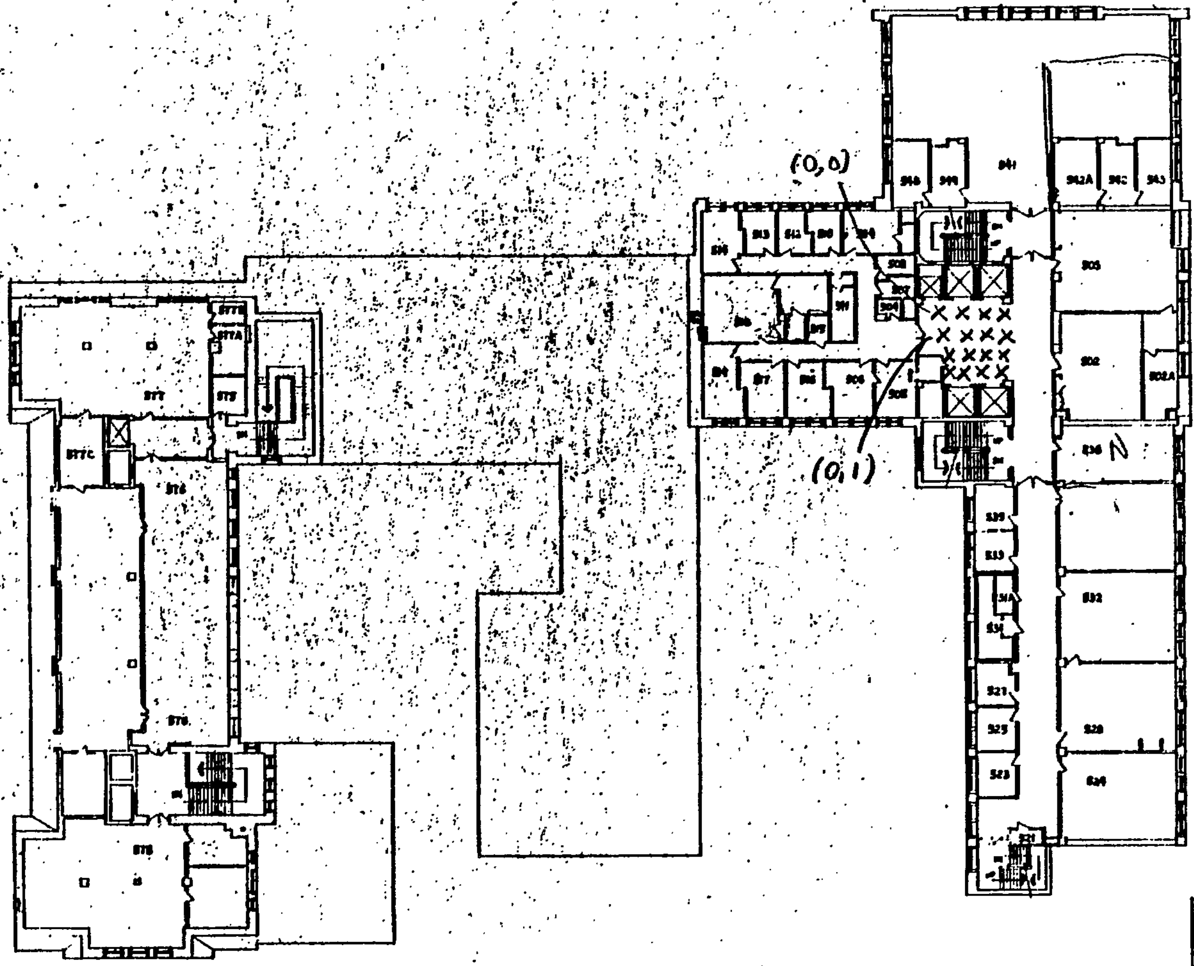
Drawn by	Patrick LEUNG		
Checked			
Scale	1/16" = 1'-0" 1:192	Dwg #	6
Date	30-04-76		

INDOOR FIELD STRENGTH MEASUREMENTS

MCCONNELL ENGINEERING BUILDING
FREQUENCY: "99 MHZ"
LOCATION: 4TH FLOOR ELEVATOR

FIELD VALUES ARE IN V/M

POSITION, Y AXIS (M) \ POSITION, X AXIS (M)	0	1	2	3
3	0.015	0.074	0.189	0.197
2	0.258	0.226	0.140	0.019
1	0.283	0.454	0.104	0.145
0	0.034	0.081	0.087	0.400

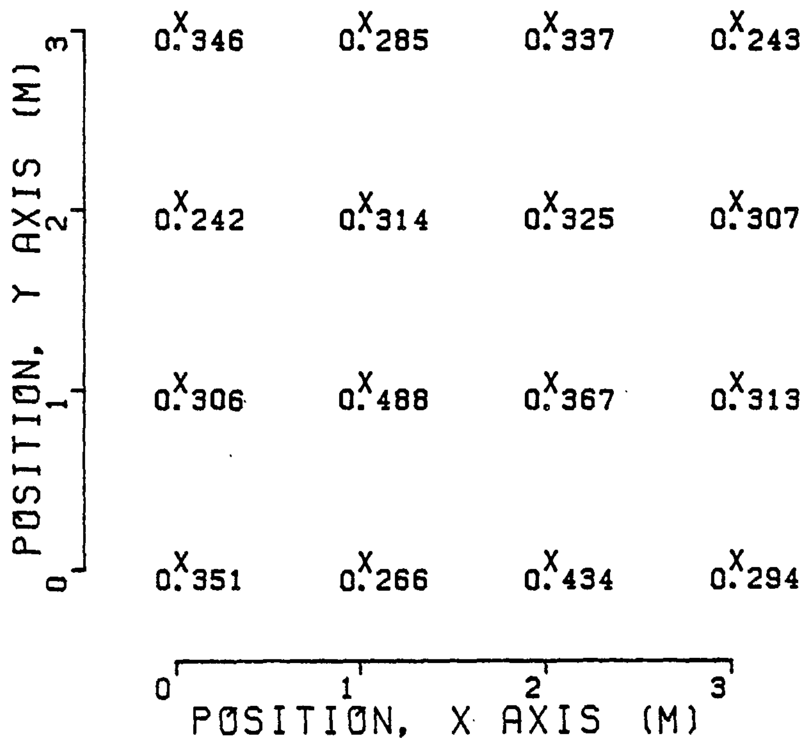


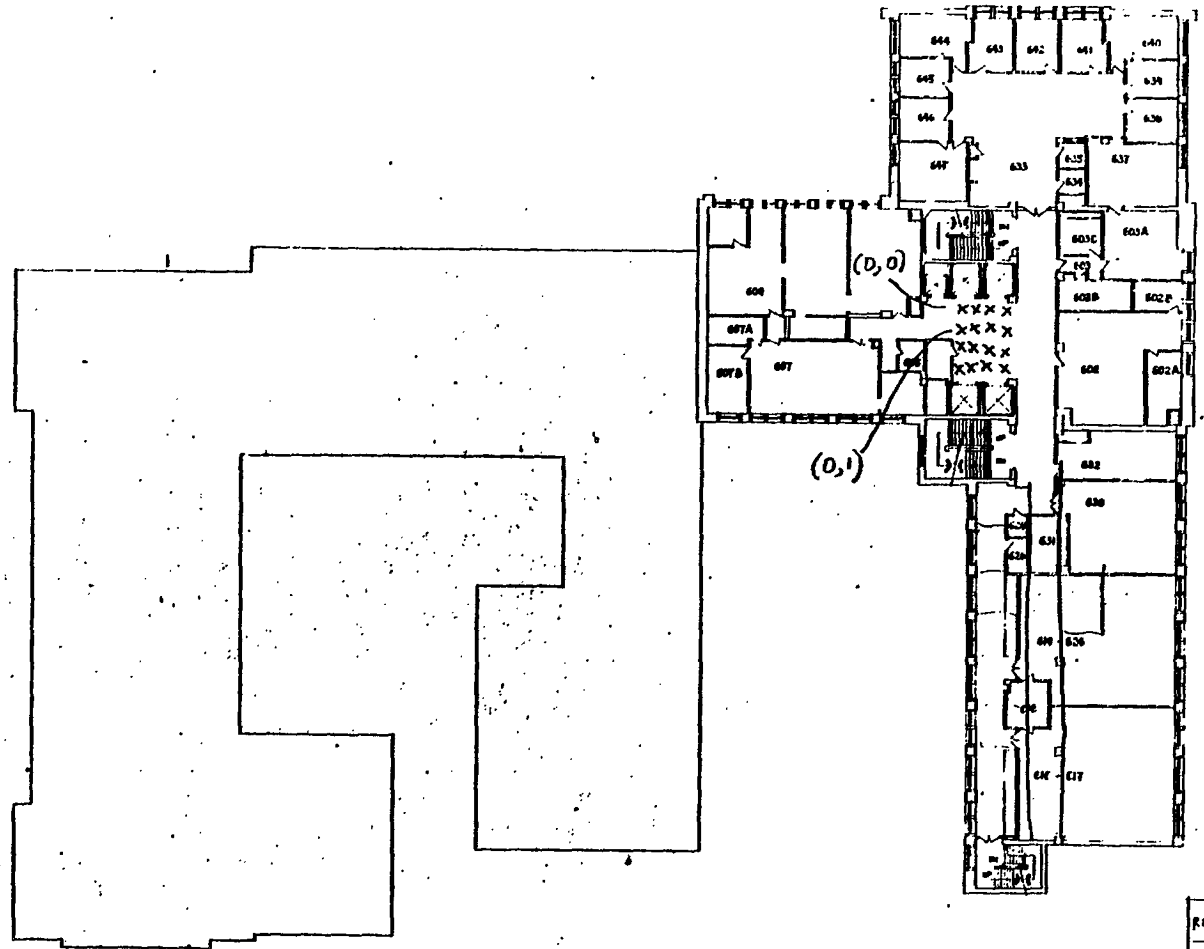
REVISED:	FEBRUARY, 1979	G. WHITELAW
FIFTH FLOOR PLAN		
Macdonald & McConnell Engineering Bldgs., McGILL		
Drawn by	Patrick LEUNG	
Checked		
Scale	1/16" = 1'-0" 1:192	Dwg # 7
Date	3-05-76	

INDOOR FIELD STRENGTH MEASUREMENTS

MCCONNELL ENGINEERING BUILDING
FREQUENCY: "99 MHZ"
LOCATION: 5TH FLOOR ELEVATOR

FIELD VALUES ARE IN V/M





REVISED	FEBRUARY: 1979.	G.WHITELAW

SIXTH FLOOR PLAN

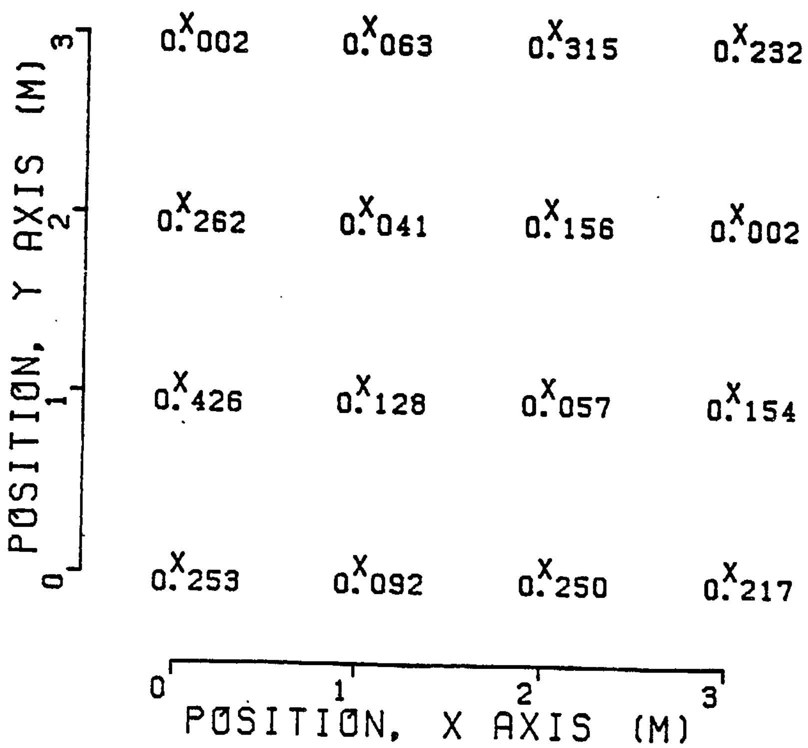
Macdonald & McConnell Engineering Bldgs, McGILL

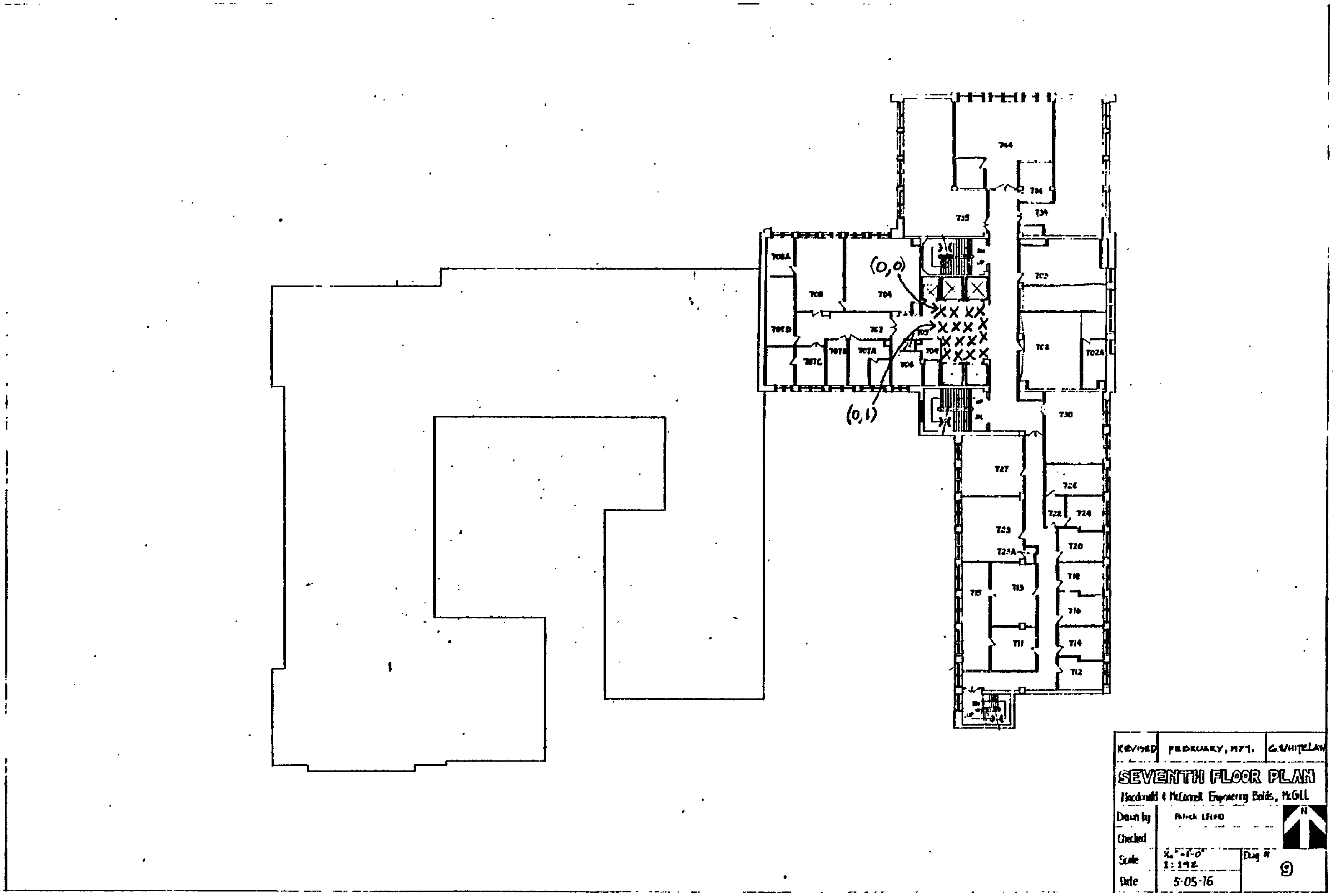
Drawn by	Patrick Leung		
Checked			
Scale	1/16" = 1'-0" 1:192	Dwg #	8
Date	5-05-76		

INDOOR FIELD STRENGTH MEASUREMENTS

MCCONNELL ENGINEERING BUILDING
FREQUENCY: "99 MHZ"
LOCATION: 6TH FLOOR ELEVATOR

FIELD VALUES ARE IN V/M




(0,0)
(0,1)
REVISED
FEBRUARY, 1977.
G.WHITELAW
SEVENTH FLOOR PLAN
Macdonald & McConnell Engineering Bldgs, McGILL
Drawn by
Checked
Scale
1:192
Date
5-05-76
Dwg #
9
N

INDOOR FIELD STRENGTH MEASUREMENTS

MCCONNELL ENGINEERING BUILDING
FREQUENCY: "99 MHZ"
LOCATION: 7TH FLOOR ELEVATOR

FIELD VALUES ARE IN V/M

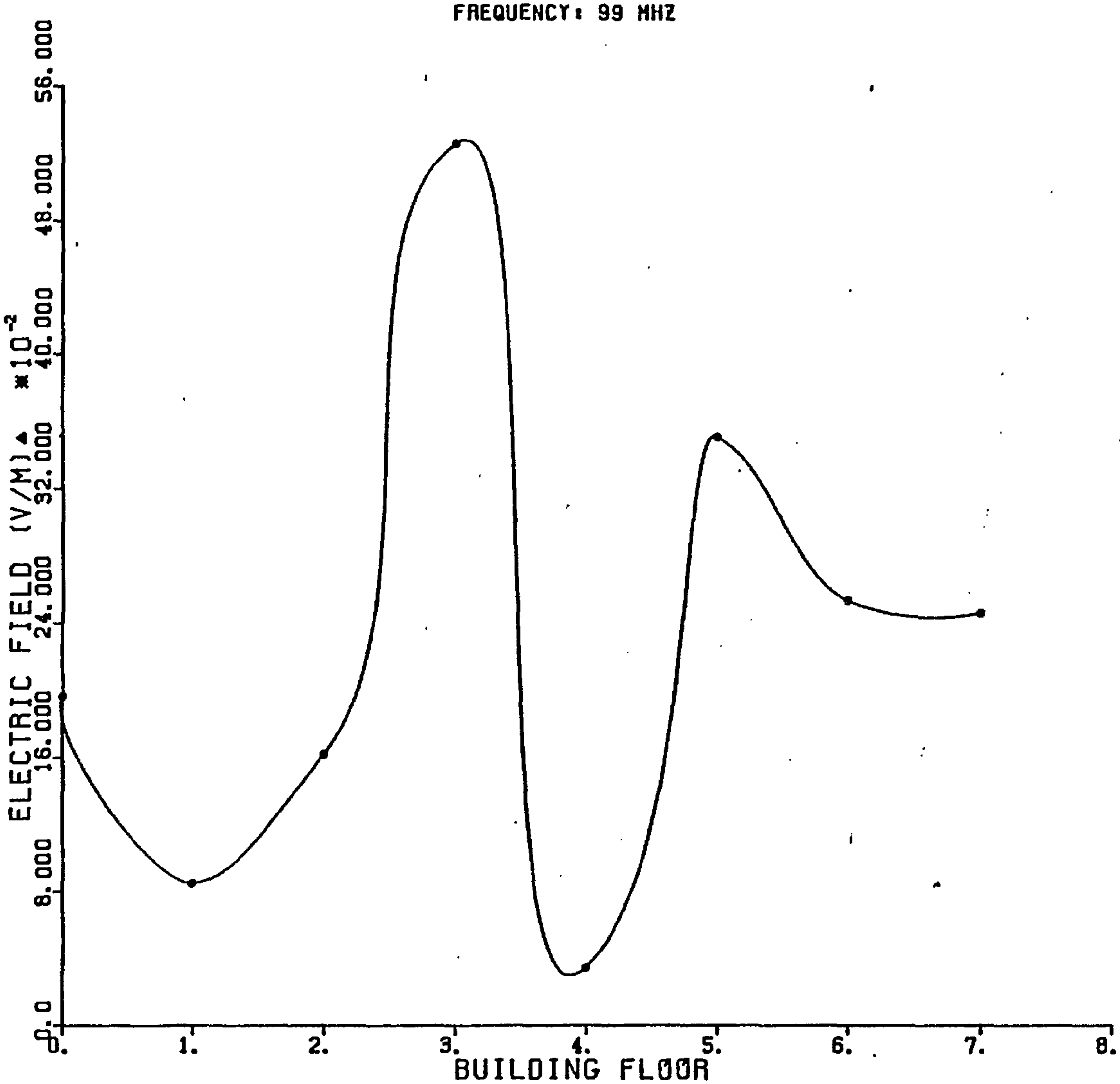
POSITION, Y AXIS (M) \ POSITION, X AXIS (M)	0	1	2	3
3	0.136	0.005	0.211	0.207
2	0.238	0.431	0.512	0.190
1	0.285	0.089	0.168	0.254
0	0.246	0.405	0.348	0.385

INDOOR FIELD STRENGTH MEASUREMENTS

MCCONNELL ENGINEERING BUILDING

POSITION: X=0, Y=0

FREQUENCY: 99 MHZ

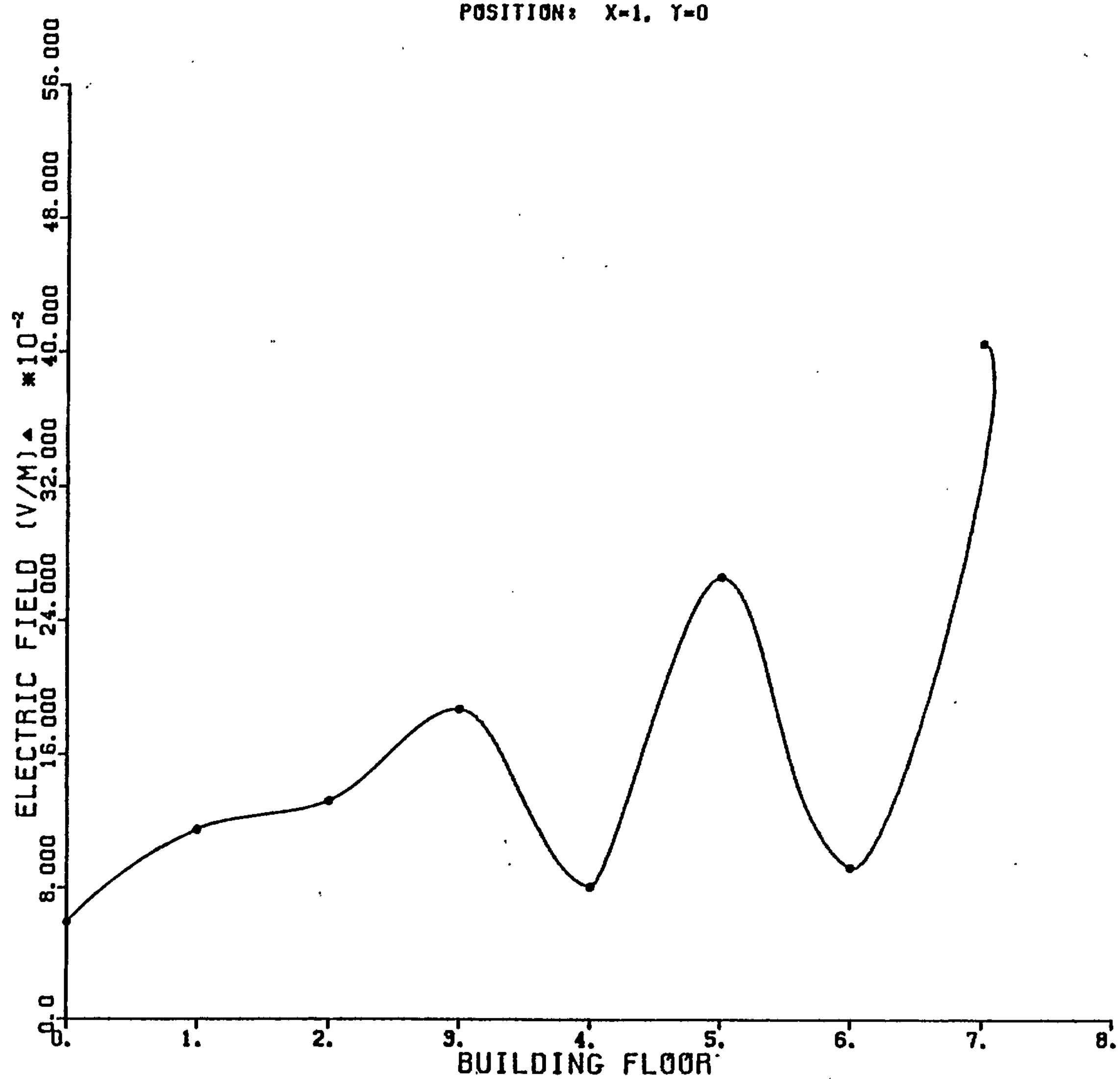


INDOOR FIELD STRENGTH MEASUREMENTS

MCCONNELL ENGINEERING BUILDING

FREQUENCY: 99 MHZ

POSITION: X=1, Y=0



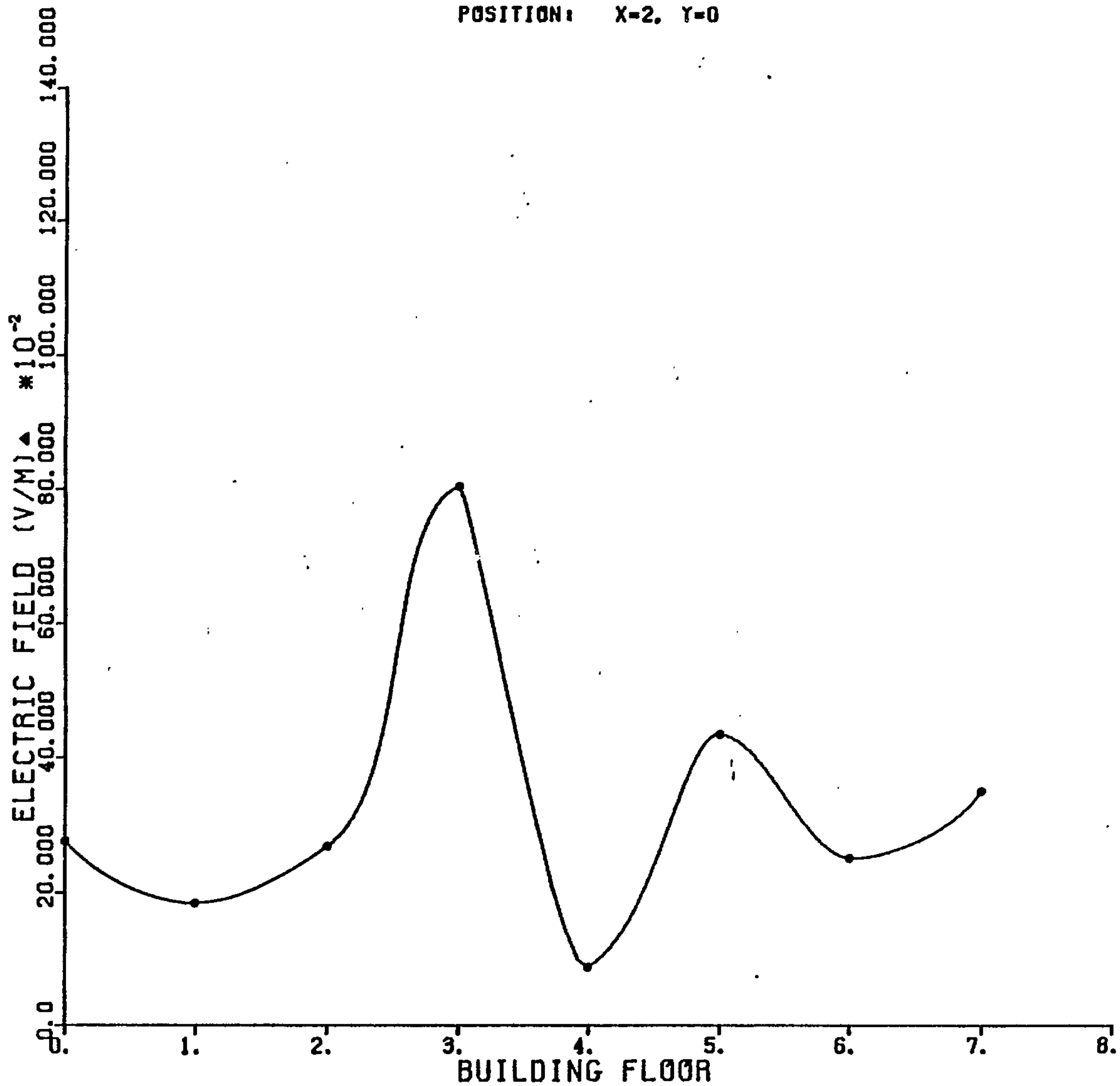
E88MUS4 WED AUG 29, 1984 12:10:11

INDOOR FIELD STRENGTH MEASUREMENTS

MCCONNELL ENGINEERING BUILDING

FREQUENCY: 99 MHZ

POSITION: X=2, Y=0



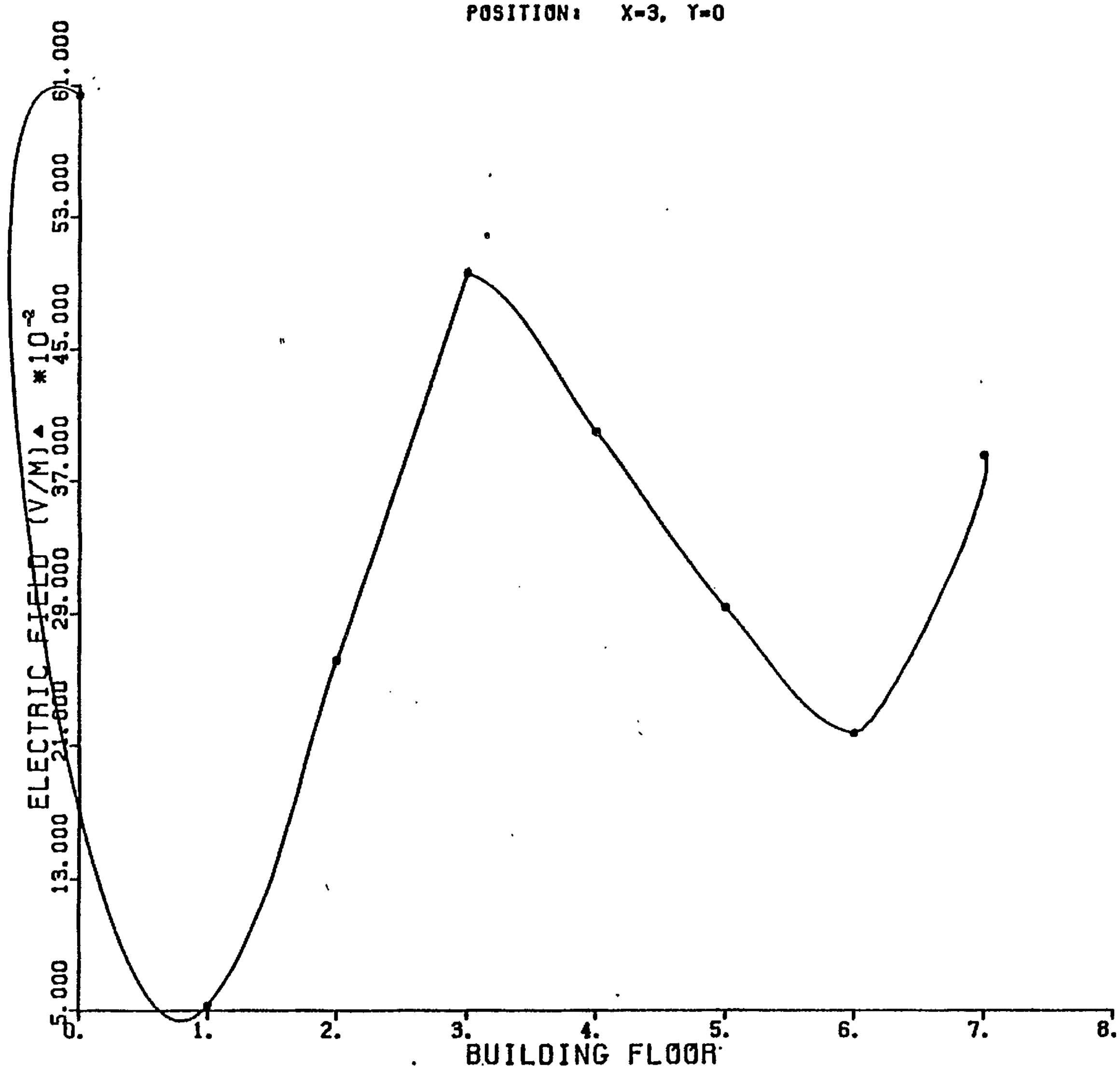
E88MUS4 WED AUG 29, 1984 12:11:16

INDOOR FIELD STRENGTH MEASUREMENTS

MCCONNELL ENGINEERING BUILDING

FREQUENCY: 99 MHZ

POSITION: X=3, Y=0



E88MUS4 WED AUG 29, 1984 12:12:26

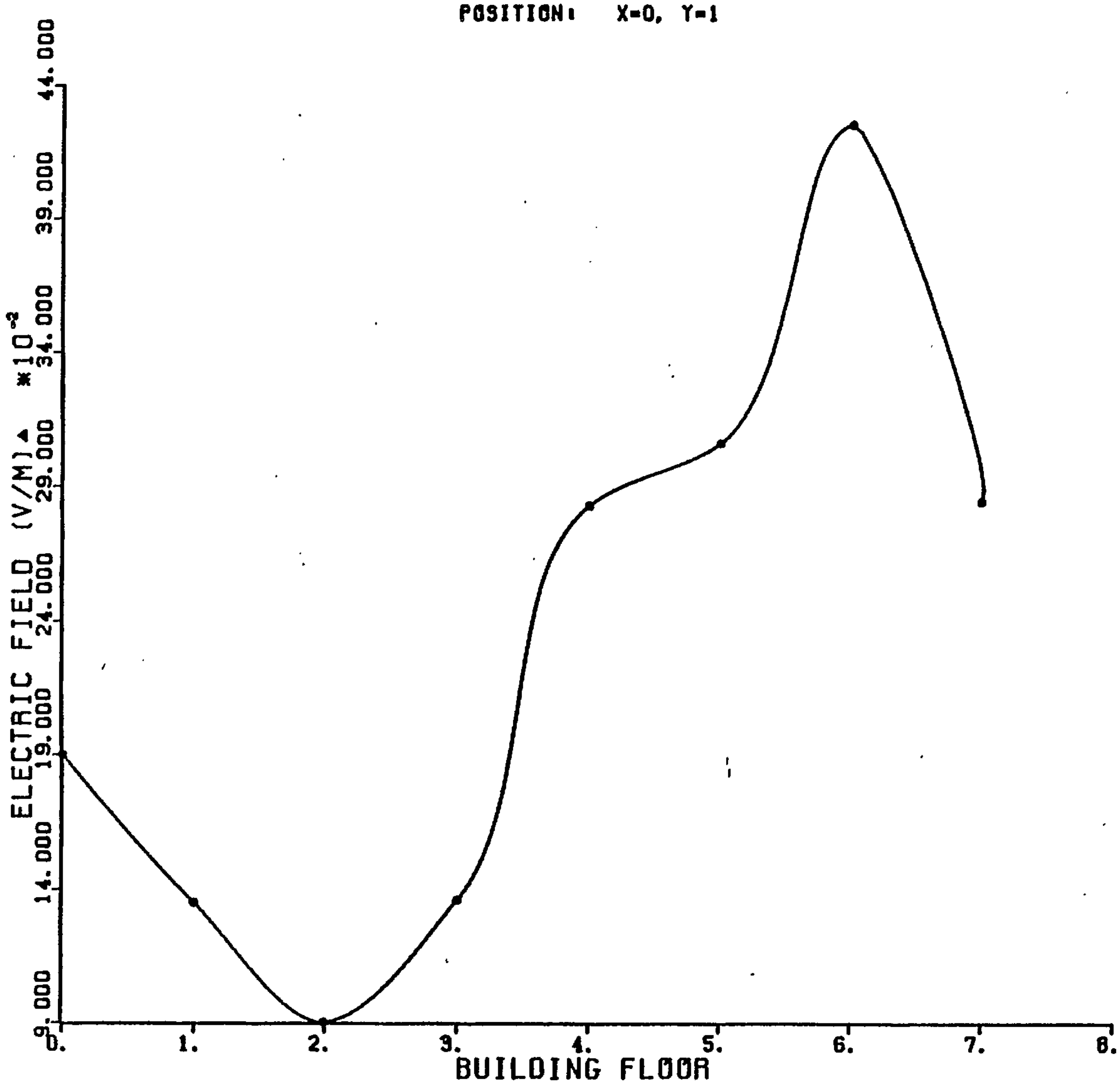
E88MUS4 FRI OCT 05, 1984 12:59:31

INDOOR FIELD STRENGTH MEASUREMENTS

MCCONNELL ENGINEERING BUILDING

FREQUENCY: 99 MHZ

POSITION: X=0, Y=1



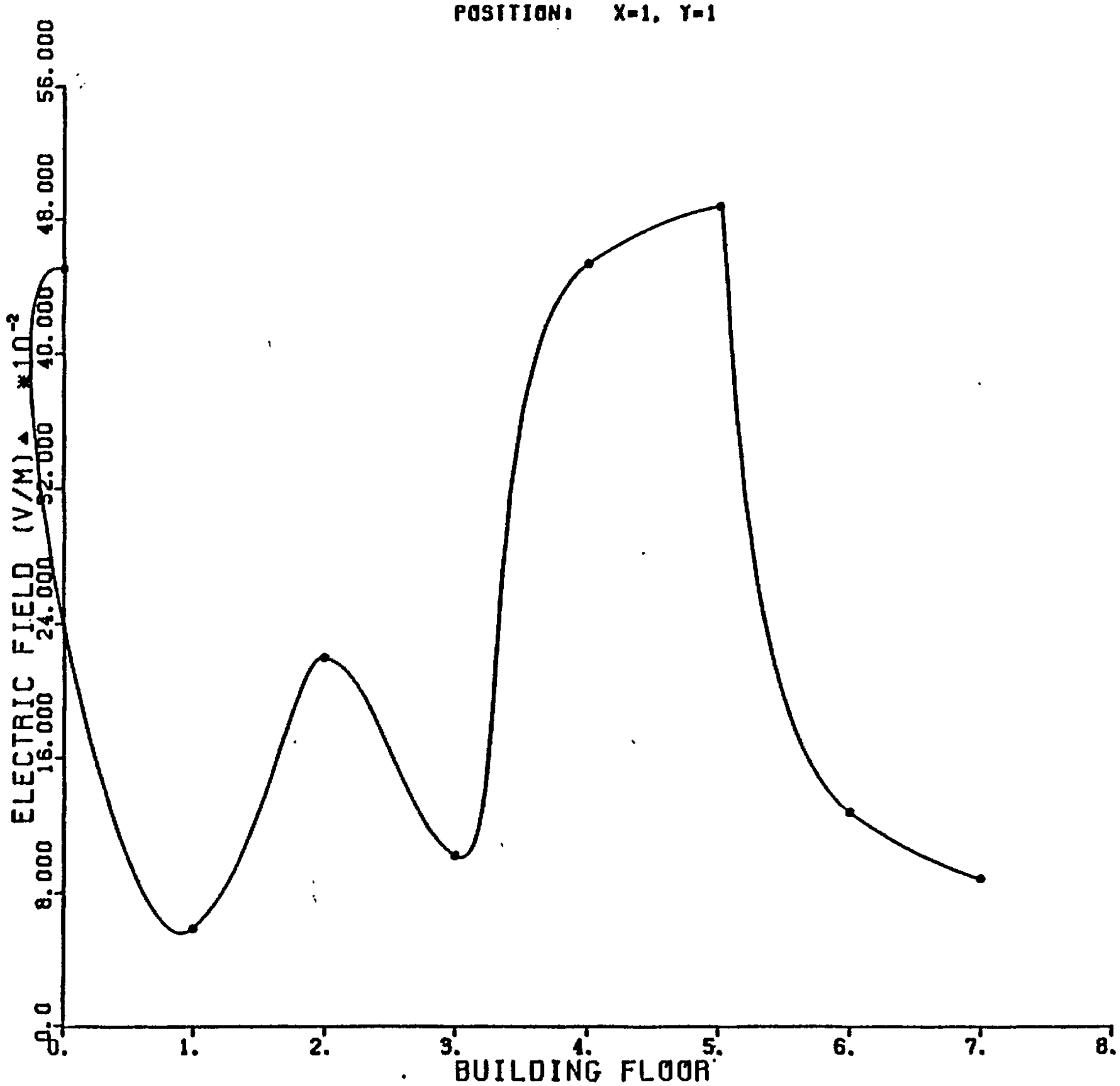
E88MUS4 FRI OCT 05, 1984 13:01:30

INDOOR FIELD STRENGTH MEASUREMENTS

MCCONNELL ENGINEERING BUILDING

FREQUENCY: 99 MHZ

POSITION: X=1, Y=1



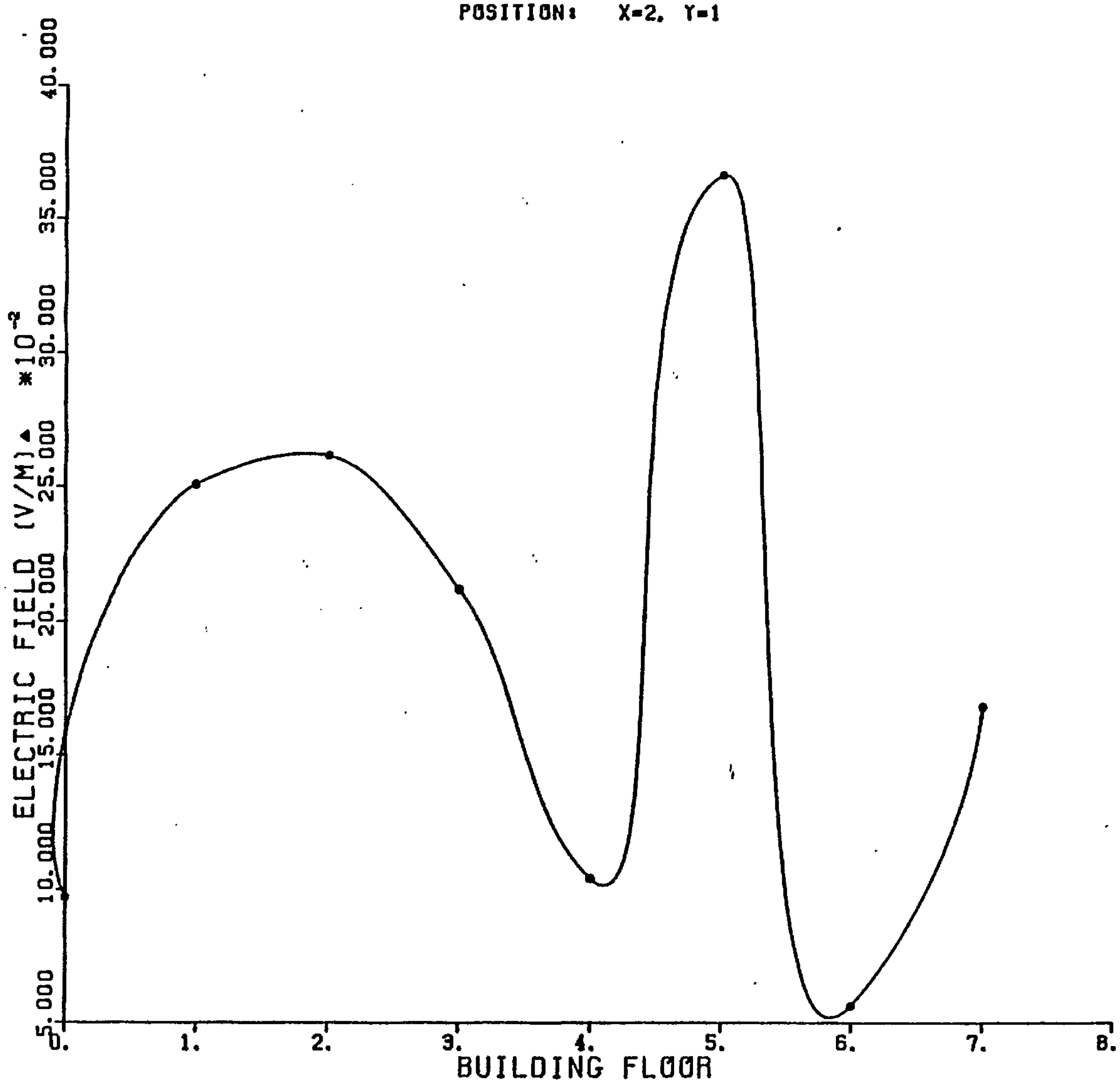
E88MUS4 WED AUG 29, 1984 12:13:45

INDOOR FIELD STRENGTH MEASUREMENTS

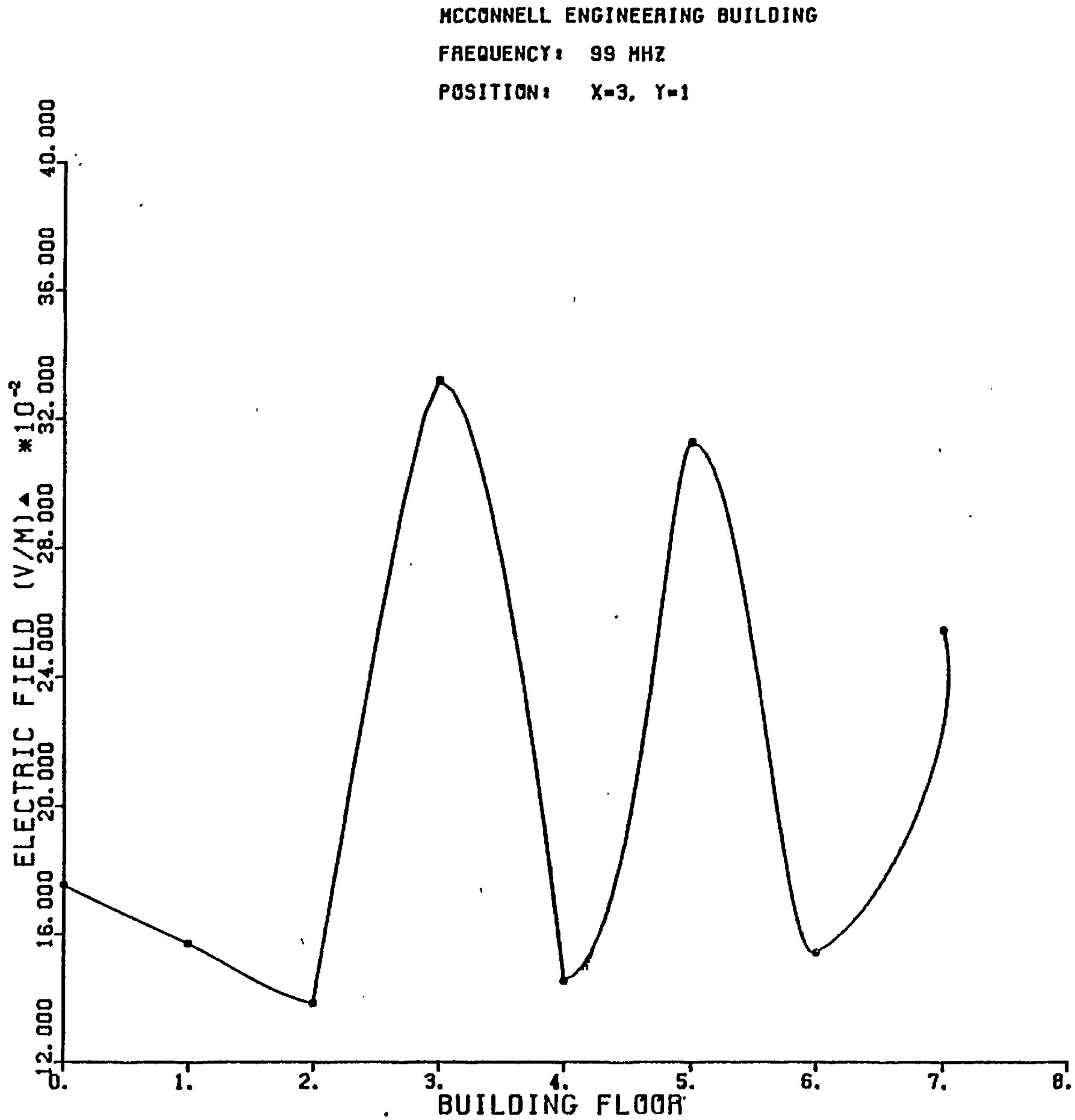
MCCONNELL ENGINEERING BUILDING

FREQUENCY: 99 MHZ

POSITION: X=2, Y=1



INDOOR FIELD STRENGTH MEASUREMENTS



E88MUS4 WED AUG 29, 1984 12:15:38

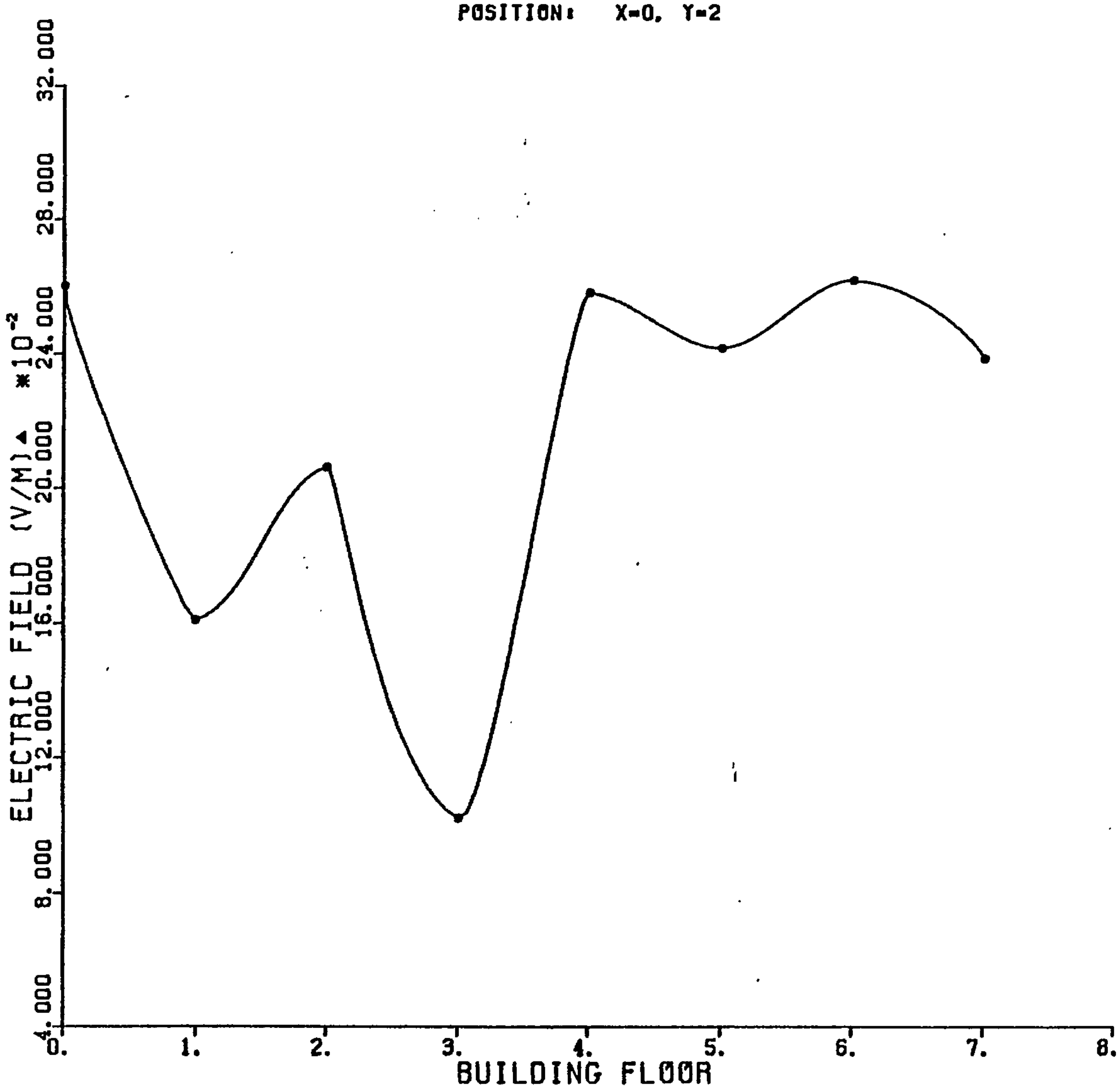
E88MUS4 WED AUG 29, 1984 12:17:34

INDOOR FIELD STRENGTH MEASUREMENTS

MCCONNELL ENGINEERING BUILDING

FREQUENCY: 99 MHZ

POSITION: X=0, Y=2

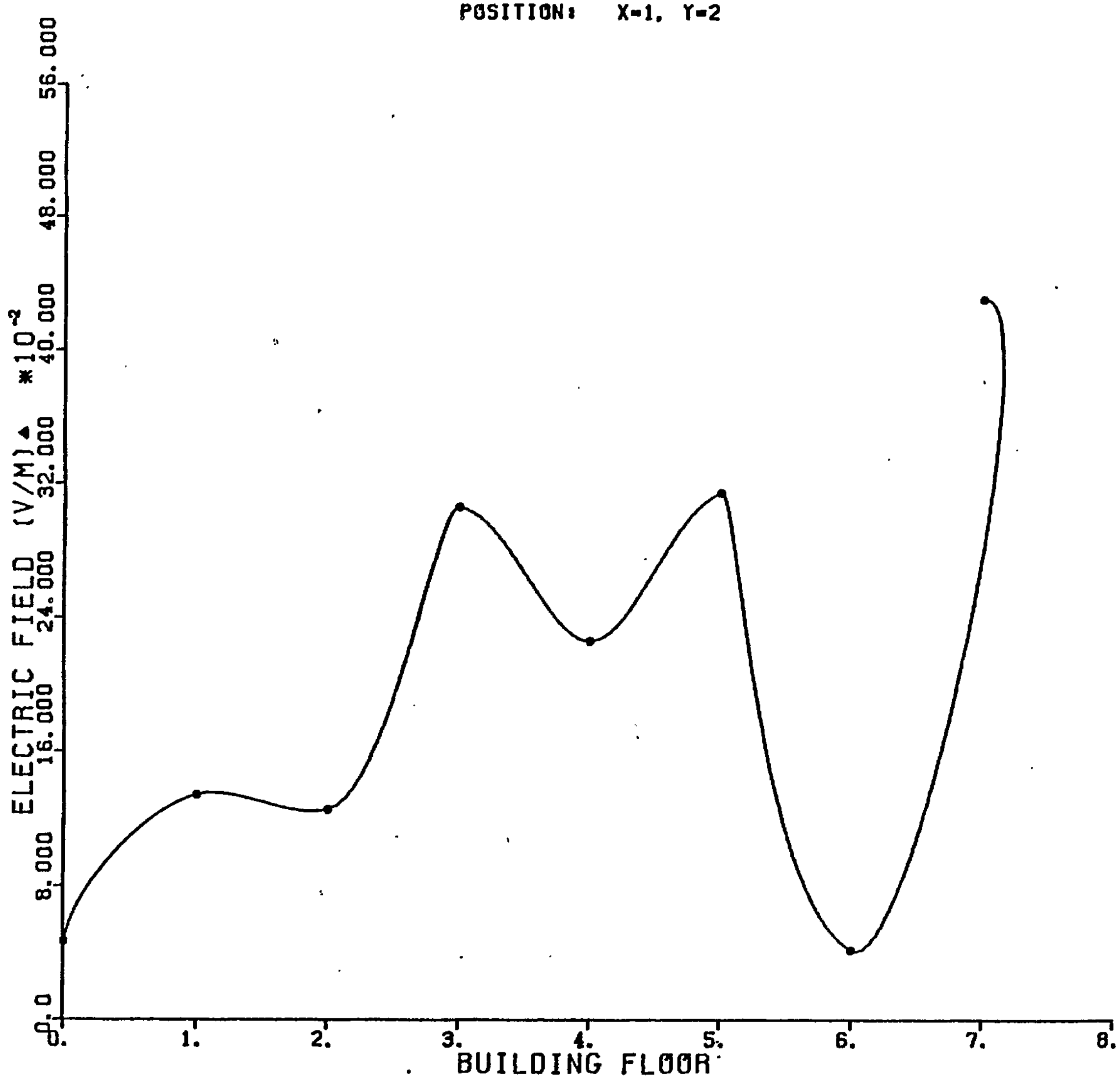


INDOOR FIELD STRENGTH MEASUREMENTS

MCCONNELL ENGINEERING BUILDING

FREQUENCY: 99 MHZ

POSITION: X=1, Y=2



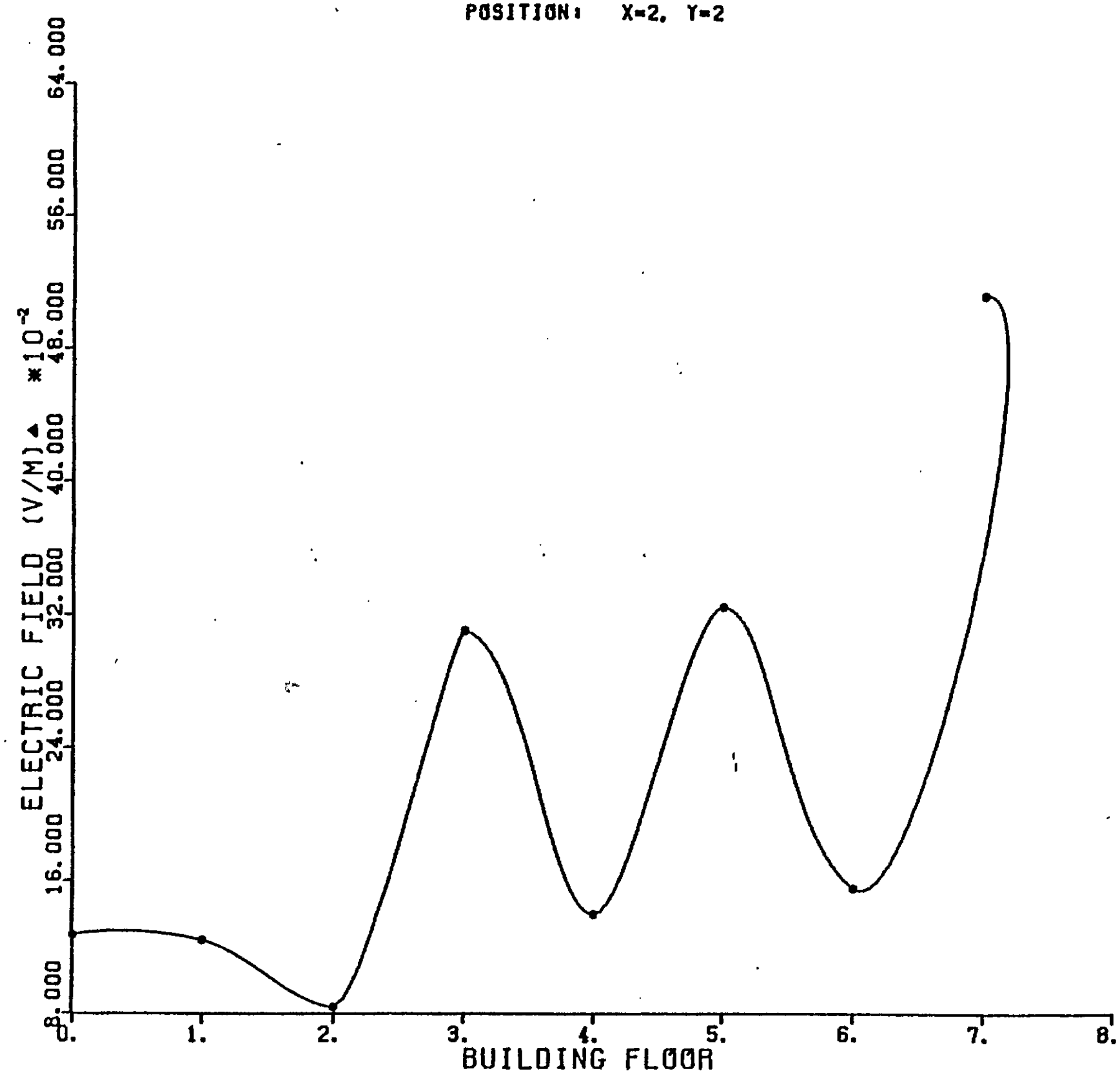
E88MUS4 WED AUG 29, 1984 12:18:37

INDOOR FIELD STRENGTH MEASUREMENTS

MCCONNELL ENGINEERING BUILDING

FREQUENCY: 99 MHZ

POSITION: X=2, Y=2



E88MUS4 WED AUG 29, 1984 12:19:42

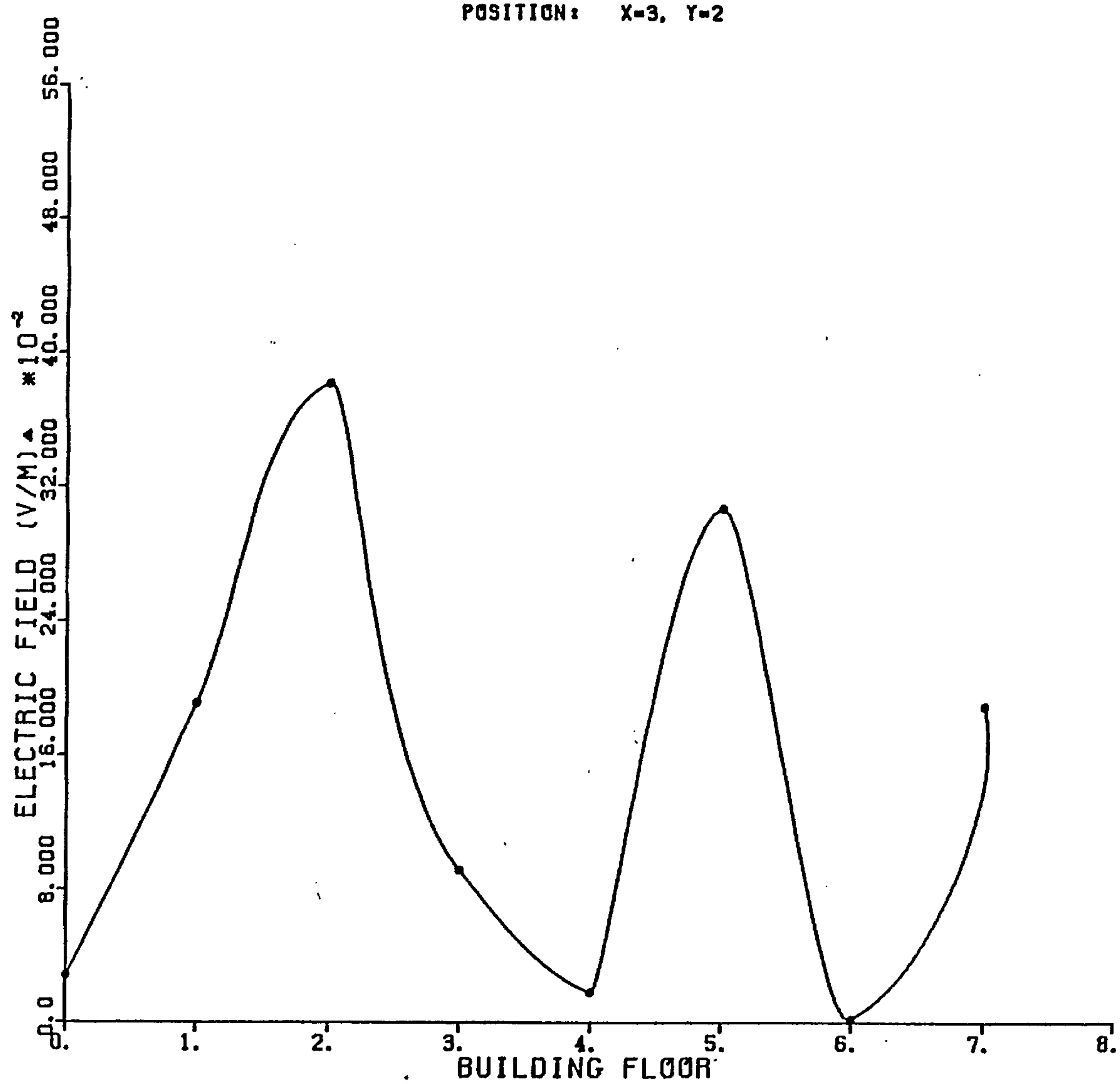
E88MUS4 WED AUG 29, 1984 12:21:36

INDOOR FIELD STRENGTH MEASUREMENTS

MCCONNELL ENGINEERING BUILDING

FREQUENCY: 99 MHZ

POSITION: X=3, Y=2

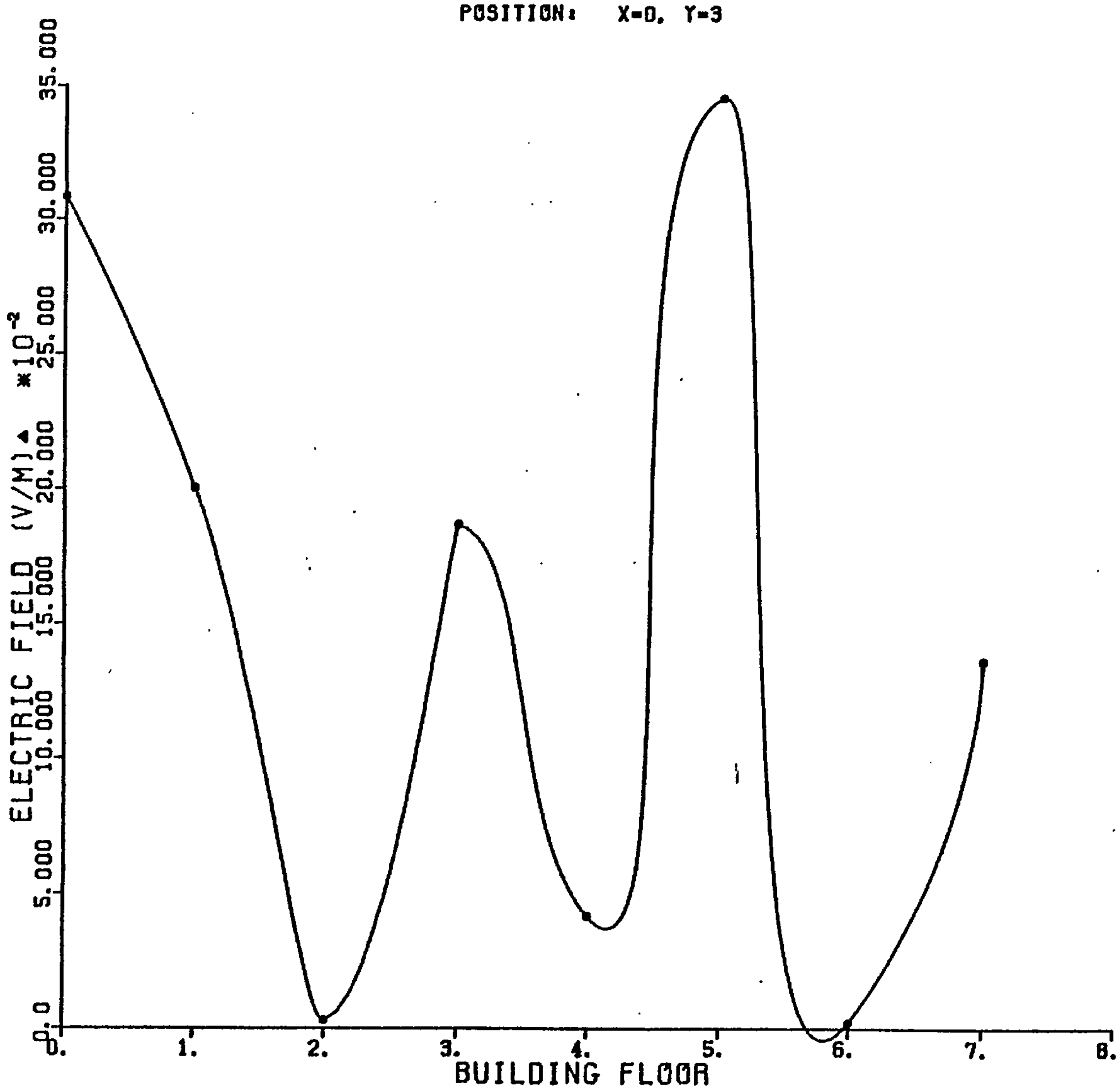


INDOØR FIELD STRENGTH MEASUREMENTS

MCCONNELL ENGINEERING BUILDING

FREQUENCY: 99 MHZ

POSITION: X=0, Y=3



E88MUS4 WED AUG 29, 1984 12:22:42

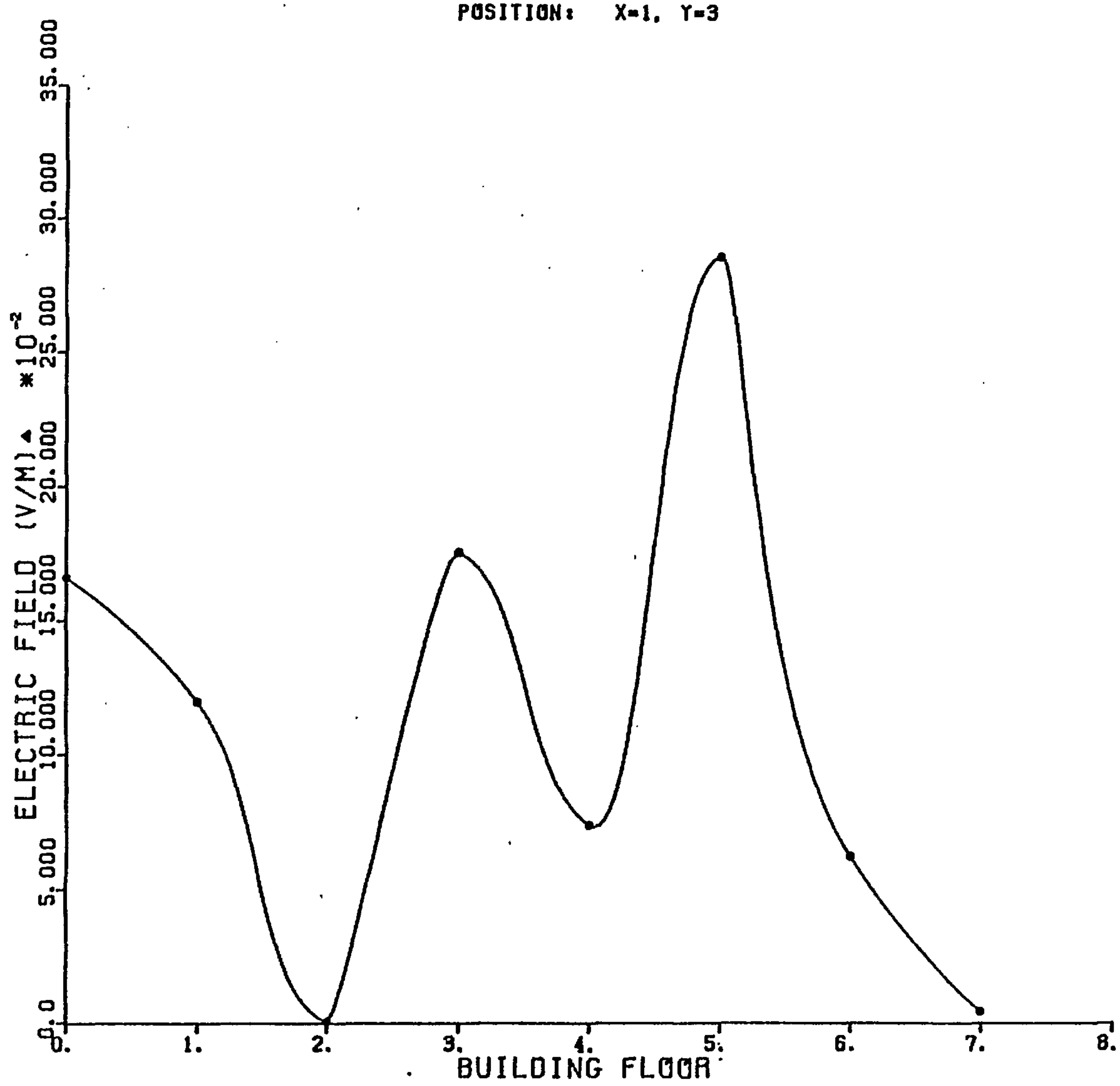
E88MUS4 WED AUG 29, 1984 12:24:31

INDOOR FIELD STRENGTH MEASUREMENTS

MCCONNELL ENGINEERING BUILDING

FREQUENCY: 99 MHZ

POSITION: X=1, Y=3

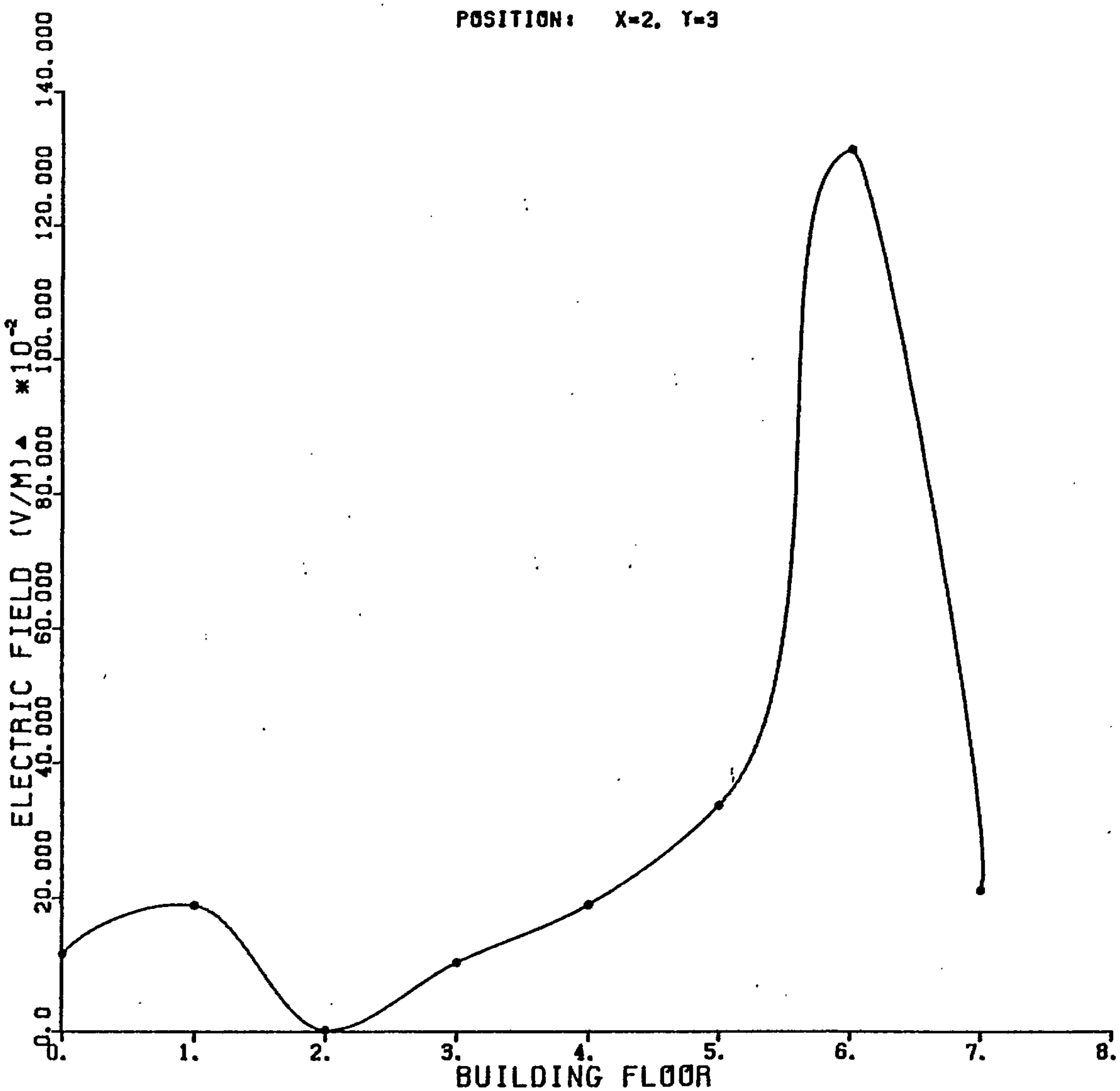


INDOOR FIELD STRENGTH MEASUREMENTS

MCCONNELL ENGINEERING BUILDING

FREQUENCY: 99 MHZ

POSITION: X=2, Y=3



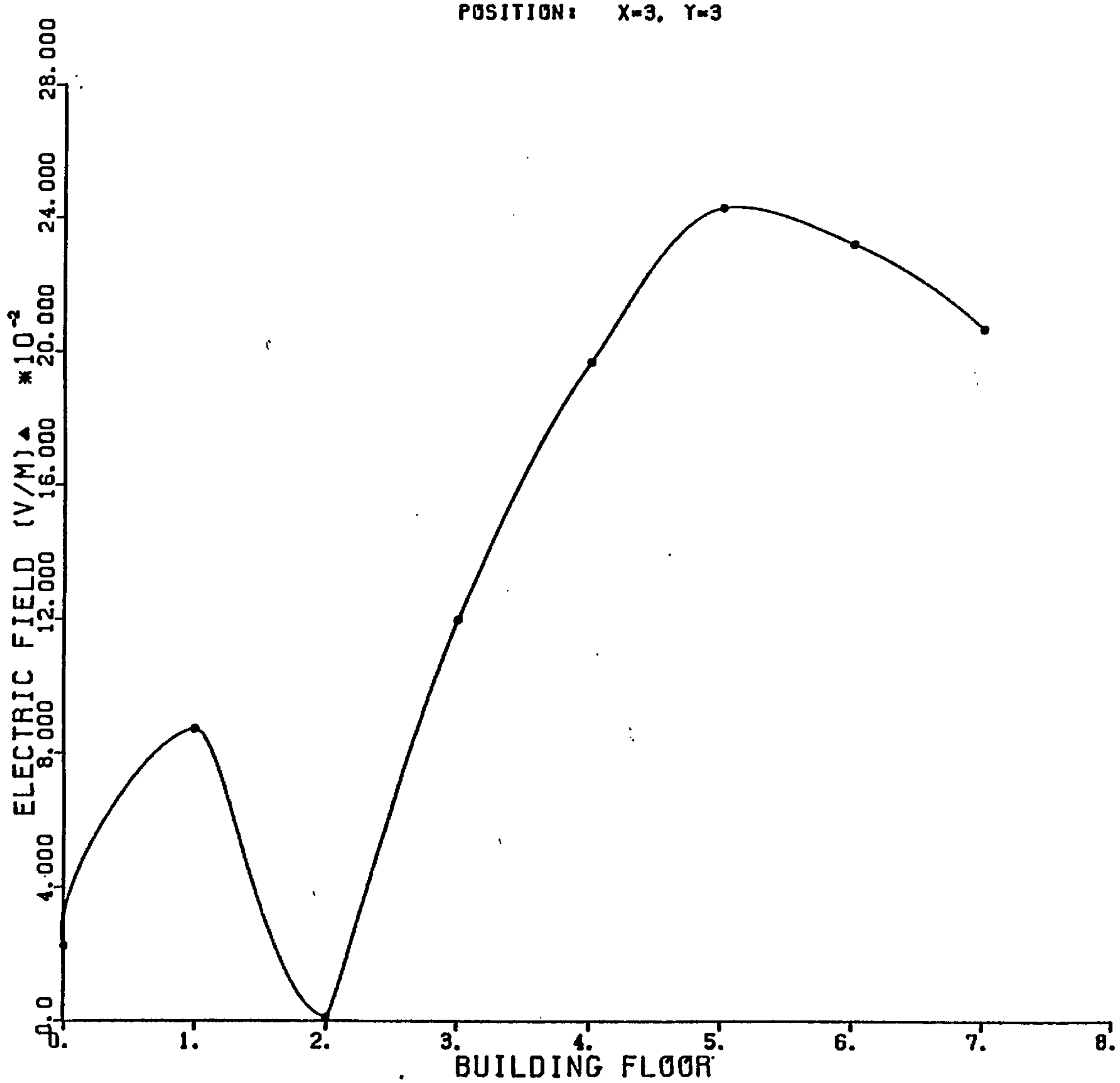
E88MUS4 WED AUG 29, 1984 12:26:40

INDOOR FIELD STRENGTH MEASUREMENTS

MCCONNELL ENGINEERING BUILDING

FREQUENCY: 99 MHZ

POSITION: X=3, Y=3



E88MUS4 WED AUG 29, 1984 12:27:34

(.3) Evaluation of Indoor Measurements.

Table (6.3.1) below presents elementary statistics of the indoor field strength data corresponding to each floor inside the McConnell Engineering Building. These statistics are based on the data as measured with a portable field strength meter inside the building. The manual recording of each measurement made it impractical to collect large amounts of data, hence the sample size was kept small (N=16) and sampling grid of one meter ($\lambda/2.5$) was used. However more extensive indoor-outdoor measurements are being planned for which a finer measurement grid (at least $\lambda/4$) will be used, and a continuous link established betweeen the indoor and outdoor field strengths.

It should be noted that the data of table (6.3.1) represent absolute field strengths (volts per meter) as given by the portable field strength meter. This data needs to be calibrated with respect to the outdoor data measured by the mobile unit in order to be meaningful. Such is the case for the data given in table (6.3.2).

Table (6.3.1). Preliminary Indoor Field Strength Measurements for the McConnell Engineering Building at 97.7 MHz (Uncalibrated to Outdoor Measurements)

Floor level	Indoor Field Strength (dBuV/m) mean	s.d.	Sample size N
Ground	105.8	103.9	16
1	102.9	94.8	16
2	103.0	101.0	16
3	108.2	106.1	16
4	104.6	102.3	16
5	110.3	96.2	16
6	104.4	101.7	16
7	108.2	102.5	16

It should be noted that for the data to give an indication of the indoor field microstructure, the number of samples per wavelength needs to be increased to at least three or four, which implies many more measurements on each floor. In such case the grid size would have to be reduced from 1 meter to about 50 centimeters. The data given in table (6.3.1) does however represent the order of magnitude of field levels to be expected when fine grained area scans are to be carried out in future, subject to the following conditions.

Firstly, from table (6.3.1) it appears that the indoor field strengths are several dB above the outdoor grade level measurements as given by table (5.5.1), however this indicates that the indoor measurements were not properly calibrated against a known reference. It was later found using a portable field strength meter that the field strength at 97.7 MHz drops by approximately 12 dB from outdoors to indoors at grade level. Knowing the approximate building attenuation at grade level thus enables the indoor data to be calibrated in absolute terms at all levels if it assumed that the building attenuation remains constant at higher elevations. Using this simple calibration scheme, and taking as reference the mean outdoor level for a route nearest to the McConnell Building (97.8 dBuV/m at 97.7 MHz), as provided by the mobile unit, the indoor data at 97.7 MHz was calibrated for all floors in absolute terms as follows:

Let OUT = mean outdoor grade level field strength in dBuV/m from mobile unit,

IN = uncalibrated indoor field strength in dBuV/m from direct measurement at each floor level,

CIN = calibrated indoor field strength in dBuV/m at each floor level,

DIFF = difference between the calibrated and uncalibrated field strengths at grade level.

Then, according to the above calibration method, the corrected indoor field strengths are given as,

1. CIN (dBuV/m) = OUT (dBuV/m) - 12 dB (grade level only)
2. DIFF (dB) = IN (dBuV/m) - CIN (dBuV/m) (grade level only)
3. CIN (dBuV/m) = IN (dBuV/m) - DIFF (dB) (floors 1-7 only)

In the above manner, the indoor field strength data as given in table (6.3.1) should all be reduced by about 20 dB. The calibrated indoor data, as given in table (6.3.2), was computed using uncalibrated data (table (6.3.1)) and a calibrating factor of 20 dB, determined as follows:

1. CIN (dBuv/m) = 97.8 dBuV/m - 12 dB (grade level only)
   = 85.8 dBuV/m
2. DIFF (dB) = 105.8 dBuV/m - 85.8 dBuV/m (grade level only)
   = 20 dB
3. CIN (dBuV/m) = IN (dBuV/m) - 20 dB (floors 1 - 7)

Table (6.3.2). Preliminary Indoor Field Strength Data for McConnell Building (97.7 MHz, Calibrated)

FLOOR LEVEL Inside McConnell Bldg.	Indoor Field Strength (dBuV/m) mean	s.d.	Sample Size N
Ground	85.8	83.9	16
First	82.9	74.8	16
Second	83.0	81.0	16
Third	88.2	86.1	16
Fourth	84.6	82.3	16
Fifth	90.3	76.2	16
Sixth	84.4	81.7	16
Seventh	88.2	82.5	16

The following observations are made of the indoor measurements as described by the above statistics:

(i) the spread in the data is large, typically less than 10 dB below the mean,

(ii) the mean levels are generally between 83 dBuV/m (0.014 V/m) and 90 dBuV/m (0.032 V/m),

(iii) the vertical profile of the field amplitude inside the McConnell Building appears to be oscillatory. This is consistent with the notion of a three-dimensional oscillatory field pattern for the em field. The oscillatory nature of the field along the vertical profile can be seen easily from the above table. It is also apparent from the plots of position versus elevation that the structure of the field changes form as a function of elevation.

It should also be noted that if a detailed structural form of the field inside the building is sought, a smaller grid size should be used (i.e., less than a quarter wavelength) in order to ensure an adequate representation of the field morphology.

(VII). DISCUSSION AND RECOMMENDATIONS

(.1) Investigation of the Outdoor EM Environment.

The purpose of the measurement of the outdoor em environment was to provide calibrated data at grade level at AM, FM and TV broadcast frequencies in a particular inner city area. This data is used to generate morphological and statistical information of the field as it exists in a city core and is then used as a reference for comparison with corresponding field strength data taken inside typical buildings in the same area.

As a case study therefore, an outdoor field strength survey was made, around the periphery and within the McGill University campus in downtown Montreal, by the C.R.C. mobile field measuring and recording unit. Measurements were made of the field strength at all the locally broadcast AM, FM, and TV frequencies along prescribed routes in the university precinct. The sampling interval was chosen to be approximately five meters (5 m). The measured data, recorded on magnetic tape, was transferred to the McGill computer system in which the data processing (plotting and statistical processing) was carried out. From the elementary statistics generated, the strongest stations were identified. These were found to be the following: CBF (690 kHz), CKOI (96.9 MHz), CITE (107.3 MHz), CBFT (59.750 MHz). The identification of the frequencies of transmitters producing the highest field levels in the area of interest, is an important step in planning measurements inside those buildings where such high levels of em radiation may cause problems in the operation of sensitive equipment such as, for example, micro-chip based devices.

(.2) Evaluation of Outdoor Survey.

Since the field strength levels for different stations vary over a wide range, it was decided to produce graphical output of the measured data using a different amplitude scale factor for each one, in order to ensure a convenient graphical display for each record. This means that for a given street, the amplitude scales are not directly comparable for the different stations, however, the choice of amplitude scales allows a convenient means of studying the data. In addition, the data was also plotted on the identical amplitude scales for selected streets. All the plots are available as an atlas as part of the resesarch project documentation, but because of their large volume, do not form part of this report.

The AM measurements are clearly a case of oversampling of the field pattern since a typical sample every five meters for a wavelength of five hundered meters represents one hundred samples per wavelength. By direct observation of the output of the AM stations, it is evident that a much coarser sampling rate would provide the same structural information provided a minimum of about three samples per wavelength is maintained. Since the field morphology is that of a three-dimensional interference pattern which is wave-length dependent, the AM fields are slowly varying with respect to distance, in contrast to the rapidly varying nature of the FM and TV field patterns.

The FM and TV field strength measurements indicate the opposite situation. Since the wavelengths are two to three orders of magnitude smaller than for the AM stations, fewer than three samples per wavelength were obtained and the field patterns were obviously undersampled. This means that the field patterns as plotted, do not reflect the structural form of the actual fields. In this case, the sampling rate needs to be increased in order to obtain an adequate number of samples per wavelength - at least three to four would be necessary.

It is therefore evident that the measurements for the FM and TV transmitters require to be repeated. However the total number of trajectories along which measurements should be repeated may be reduced since the orders of magnitude of the fields are known for several streets and, secondly, only the patterns of the strongest stations would be of interest. Hence a second outdoor field survey of the FM and TV stations at a much higher sampling rate (e.g. four samples per wavelength minimum) is recommended, to provide the fine grain detail of the FM and TV fields as is already available in the case of the AM stations. This second survey thus would be a repetition of the previous survey, but only for a reduced set of routes and frequencies. The routes would be those in the immediate vicinity of the buildings to be surveyed indoors and meaurements would be made only for the strongest local FM and TV transmitters.

In order to describe an actual electric field profile in detail, many samples per wavelength must be taken. This is some conflict with the requirements for random sampling needed to obtain valid statistics on the distribution of the electric field(s) in a given area. In that case the samples should be decorrelated, that is, must be independent from each other. This mitigates against using samples too closely related in space. For this purose, samples taken 0.8λ or more apart may be used under certain circumstances. Nevertheless, an adequate number of samples must be used in order to reduce the margin of uncertainty to acceptable levels.

It is a notable aspect of the present measurements that while the primary purpose has been to carry out a statistical evaluation, it was nevertheless also of interest to obtain, if possible, a feeling for the actual structure (morphology) of the field profiles. The 'pattern' of measurements required for "good statistics" thus appears to be somewhat in contradiction to that indicated for determining the "field structure" as well. It is suggested that the decorrelation may be achieved by a judicial statistical choice of data obtained by the closely spaced measurements.

(.3) Comparison of Indoor and Outdoor Measurements.

Indoor measurements were made in the McConnell Engineering Building, located at the corner of University and Milton Streets. Three of the outdoor survey routes pass by and intersect at the main entrance of the building, thus providing adequate outdoor data for comparison. This section compares the outdoor measurements with some preliminary indoor field strength data for a particular FM transmitter and provides a tentative estimate of building attenuation for the McConnell building.

Only rudimentary equipment was available to make the exploratory survey of the indoor fields and to assess the outdoor to indoor attenuation. The indoor measurements were first made at 96.9 MHz (CKOI), however it was found that the output intermediate frequency (IF) stages were frequently being saturated, thus yielding non comparable measurements. The indoor measurements were therefore repeated at a weaker station, namely at 97.7 MHz (CHOM).

In order to estimate the attenuation provided by a building, the outdoor level (in dBuV/m) is compared against the indoor level (in dBuV/m), the difference being the approximate attenuation (in dB) of the building. The indoor data used in such studies must be calibrated in the same manner as the outdoor data for generating meaningful estimates of the attenuation. The indoor data, obtained with a portable field strength meter, was therefore calibrated relative to the mean outdoor level measurement, made by the C.R.C. survey vehicle, which was used as the "correct" reference. It is this "recalibrated" data which is used in estimating the building attenuation (at grade level). Table (7.3.1) summarizes the measured results obtained from the oudoor grade level survey near the McConnell Building and the preliminary indoor survey inside the McConnell Building.

Table (7.3.1). Outdoor and Indoor Measurements Obtained at 97.7 MHz and Estimate of Building Attenuation of the McConnell Engineering Building at Grade level.

Floor Level	Route Number	Outdoor Level (dBuV/m)			Indoor Level (dBuV/m)			Attenuation (dB)	
		N	mean	s.d.	N	mean	s.d.	mean	s.d.
GROUND	1	319	90.8	85.6	16	85.8	83.9	5.0	1.7
GROUND	13 (*)	288	97.8	93.2	16	85.8	83.9	12.0	9.3
GROUND	17	226	93.4	87.6	16	85.8	83.9	7.6	3.7
FIRST					16	82.9	74.8		
SECOND					16	83.0	81.0		
THIRD					16	88.2	86.1		
FOURTH					16	84.6	82.3		
FIFTH					16	90.3	76.2		
SIXTH					16	84.4	81.7		
SEVENTH					16	88.2	82.5		

(*) : Route # 13 is closer to the McConnell Building Main Entrance than are routes # 1 or 17. The attenuation value for this route is the one used in calibrating the indoor measurements.

The measurements indicate that the indoor levels exhibit an oscillatory nature along the vertical profile of the building. This pattern can be explained by the three-dimensional interference pattern nature of the electromagnetic field. In addition the structure of the field changes form as a function of elevation.

It is also obvious that in order to estimate the degree of signal attenuation at higher elevations, an appropriate vertical profile of the outdoor field strengths needs to be made, using some appropriate measuring apparatus suspended from the roof of the building and maintained at several distances away from it, if an indication of the structure is to be obtained.

It may be anticipated that, since the FM transmitter is within sight from the McConnell Building, that there would be progressively higher field strengths as the elevation increases above grade level, since the FM transmitting antenna is positioned to provide maximum radiation when the angle of depression is zero. In one instance, for example, the field strength on the top of the McConnell Building was found to cause saturation of the field strength meter, indicating a field strength above 2.0 volts per meter at 107.3 MHz. A corresponding measurement at grade level just outside the McConnell Engineering Building, indicated a field strength of approximately 0.5 V/m.

(.4) CONCLUSIONS

In the present report, the following points have been discussed:

1. Calculation of free space field levels at the McGill campus, due to all local AM, FM, and TV transmitters, based on a simple free space direct wave propagation model;

2. Presentation of results of the outdoor grade level survey by the C.R.C. mobile field measuring unit;

3. Comparison of predicted free space levels with measured outdoor data through the use of elementary statistical processing;

4. Identification of the strongest stations from the outdoor survey data and a description of their corresponding mean field strengths near the McConnell Engineering Building;

5. Preliminary exploration of the structure and behaviour of indoor field strength data at one FM frequency;

6. Comparison of outdoor and indoor data at grade level, and an assessment of the building attenuation.

The size of the measurement data bank is an important concern in processing the data recorded by the mobile unit. Memory size limitations and inefficient transfer of data from magnetic tape to disk may prove to be major problems in processing a large amount of data on a particular computer system. For certain types of applications such as plotting, for example, operator assistance is required resulting in greater delays and higher costs in obtaining computerized output. In the present study the factors most crucial to obtaining efficient data processing are the system's ability to create and store large data files (containing upto 5 000 records each), its ability to transfer data efficiently from magnetic tape onto disk (i.e. small turnaround times), its ability to plot the data on a high speed plotter with adequate resolution capacity, its ability to submit batch jobs in the case of repetitive processing of the same program, and finally its ability to communicate interactively with a user at a terminal for software development and testing.

Interestingly, it was found that one of the four strongest stations identified is the AM station, CBF, at 690 kHz. It will be useful to make corresponding indoor measurements for this transmitter. The attenuation due to the building at the AM frequencies can then be compared with that at the FM and TV frequencies, particularly for the strong signals due to CITE (107.3 MHz), CKOI (96.9 MHz), and CBFT (59.75 MHz). A study of the UHF transmitter, CIVM (489.25 MHz) should also be of interest, especially at the higher elevations, because of this transmitter's very high radiated power, combined with a very narrow beam.

(VIII). REFERENCES

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APPENDICES

APPENDIX (A):
DATA PROCESSING AND PLOTTING SOFTWARE
DEVELOPED ON McGILL UNIVERSITY COMPUTER SYSTEM (MUSIC)
(Program Listings)

```
list read.doc4
RETURN
//EE88READ JOB (EE88,001,005,400,0000,23,,1)
//*PASSWORD=PEMV
    EXEC SETUP
    SIN DD *
T9=AA0635(RO,AL,SLOT=P-82)
// EXEC PGM=IEBGENER
//SYSPRINT DD SYSOUT=A
//SYSIN DD DUMMY
//SYSUT2 DD SYSOUT=A
//SYSUT1 DD VOL=SER=AA0635,DISP=OLD,LABEL=(2,AL),DSN='PREPRO',
// UNIT=TAPE9,DCB=(OPTCD=Q,DEN=3,RECFM=FB,LRECL=128,BLKSIZE=4096)
//
*End
*Go
```

```
list read.doc5
RETURN
//EE88READ JOB (EE88,001,005,400,0000,23,,1)
//*PASSWORD=PEMV
//  EXEC SETUP
//SYSIN DD *
T?=AA0965(RO,SL,SLOT=P-98)
   EXEC PGM=IEBGENER
   /SPRINT DD SYSOUT=A
  SYSIN DD DUMMY
//SYSUT2 DD SYSOUT=A
//SYSUT1 DD VOL=SER=AA0965,DISP=OLD,LABEL=(2,SL),DSN=MOFTTD,
// UNIT=TAPE9,DCB=(DEN=3,RECFM=FB,LRECL=128,BLKSIZE=4096)
// EXEC PGM=IEBGENER
//SYSPRINT DD SYSOUT=A
//SYSIN DD DUMMY
//SYSUT2 DD SYSOUT=A
//SYSUT1 DD VOL=SER=AA0965,DISP=OLD,LABEL=(3,SL),DSN=MOAMTD,
// UNIT=TAPE9,DCB=(DEN=3,RECFM=FB,LRECL=128,BLKSIZE=4096)
// EXEC PGM=IEBGENER
//SYSPRINT DD SYSOUT=A
//SYSIN DD DUMMY
//SYSUT2 DD SYSOUT=A
//SYSUT1 DD VOL=SER=AA0965,DISP=OLD,LABEL=(4,SL),DSN=MOAMRD,
// UNIT=TAPE9,DCB=(DEN=3,RECFM=FB,LRECL=128,BLKSIZE=4096)
//
*End
*Go
```

```
/FILE 3 NAME(MCGILL.AFT) LR(128) SHR
/LOAD FORTG1
C ************************************************************************
C         FILE:    BOB.MAIN
C         DATE:    MARCH 1984
C         WRITTEN BY:  T.BANIK
C ________________________________________________________________________
C  THIS PROGRAM READS FIELDSTRENGTH DATA OBTAINED FROM THE STREET LEVEL
C MEASUREMENTS MADE BY THE DOC'S MOBILE SCANNING UNIT IN MARCH 1983.
C THE PROGRAM READS IN THE  DESIRED STATION,FREQUENCY, STREET OF TRAVEL,
C INTERSECTING STREET; THE PROGRAM OUTPUTS - FOR THE SPECIFIED STATION
C AND STREET - THE FIELD VERSUS POSITION DATA ALONG STREET OF TRAVEL,AND
C STORES THIS INFORMATION IN A FILE FOR SUBSEQUENT PROCESSING (I.E.
C X - Y  PLOTTING USING A DIGITAL PLOTTER).
C ************************************************************************
       REAL*8 ARRAY(40),STN
       REAL FREQ,WAVL
       LOGICAL*1 RECORD(128),ANSWER(3),EQUAL
       INTEGER UNIT/2/,IREC
       DATA YES/'YES'/,NO/'NO'/
       DATA ARRAY/'CFCF.VA','CBF.VA','CKAC.VA','CJAD.VA','CKVL.VA',
     ^ 'CBM.VA','CKGM.VA','CHRS.VA','CJMS.VA','CFMB.VA',
     ^ 'CKO.VA','CKLM.VA','CBFT.VT','CBMT.VT','CFQR.VF',
     ^ 'CBM.VF','CKMF.VF','CJFM.VF','CKOI.VF','CHOM.VF',
     ^ 'CBF.VF','CINQ.VF','CFGL.VF','CITE.VF','CBFT.HT',
     ^ 'CBMT.HT','CFQR.HF','CBM.HF','CKMF.HF','CJFM.HF',
     ^ 'CKOI.HF','CHOM.HF','CBF.HF','CINQ.HF','CFGL.HF',
     ^ 'CITE.HF','CFTM.HT','CFCF.HT','CFTM.VT','CFCF.VT'/
C
2      REWIND 3
       CALL SETINF(400)
       CALL OPNFIL(UNIT,K,'&&TEMP','OKNEW WROK.')
       CALL FILMSG(K,UNIT)
C
C**********************************************************************
C   THIS IS THE MAIN PROGRAM SECTION.  IN THIS SECTION, THE NAME OF
C THE DESIRED STATION IS READ.  ONCE THE FIELD STRENGTH VS POSITION
C DATA HAVE BEEN FOUND, WHICH IS DONE IN SUBROUTINES STDAT AND POSFLD,
C THE MAIN PROGRAM CREATES A FILE THAT STORES THE APPROPRIATE FIELD VS
C POSITION DATA FOR THE DESIRED STATION AND STREET OF TRAVEL.
C   THE MAIN PROGRAM THEN ASKS IF ANY FURTHER STATIONS ARE REQUIRED;
C IF MORE STATIONS ARE DESIRED, THE PROGRAM LOOPS BACK AND REPEATS
C THE PROCESS ABOVE UNTIL NO FURTHER STATIONS ARE DESIRED.
C**********************************************************************
C
C      READ IN THE FIRST RECORD FROM TAPE: IF TYPE 2, WRITE RECORD,
C      OTHERWISE SKIP TO REORD TYPE 6.
C
       READ(3,5) RECORD
5      FORMAT(128A1)
       CALL CORE(RECORD,128)
6      READ(3,50) IREC
       IF(IREC.EQ.2) WRITE(6,5) RECORD
       IF(IREC.NE.2) GO TO 12
       READ(3,5) RECORD
```

```
C  ENTER THE DESIRED STATION AND FREQUENCY:
10     REWIND 3
12     WRITE(6,15)
15     FORMAT('ENTER STATION:')
       READ(9,20) STN
20     FORMAT(A7)
       WRITE(6,25)
25     FORMAT('ENTER STATION FREQUENCY IN KHZ:')
       READ(9,*) FREQ
C  LOCATE POSITON OF STATION IN ARRAY OF LENGTH 40:
       DO 30 I=1,40
       IF(STN.EQ.ARRAY(I))IPOS=I
30     CONTINUE
C  IDENTIFY THE STATION, POSITON,FREQUENCY,WAVELENGTH:
       WRITE(6,35)
       WRITE(UNIT,35)
35     FORMAT('ELECTRIC FIELD STRENGTH VS POSITION')
       WRITE(6,40) ARRAY(IPOS),IPOS
       WRITE(UNIT,40)ARRAY(IPOS),IPOS
40     FORMAT('STATION:',1X,A7,5X,'ARRAY POSITION:',1X,I2)
       WAVL = 300000./FREQ
       WRITE(6,45) FREQ,WAVL
       WRITE(UNIT,45) FREQ,WAVL
45     FORMAT('FREQUENCY (KHZ):',1X,F9.2,4X,'WAVELENGTH (M):',E9.3)
C
C   SEARCH FOR THE DESIRED STREET AND FIELD STRENGTH DATA
C   BY CHECKING THE RECORD TYPE AND CALLING APPROPRIATE SUBROUTINES:
C
       CALL CORE(RECORD,128)
       READ(3,50) IREC
50     FORMAT(1X,I2)
       IF(IREC.EQ.6) CALL STDAT(UNIT,RECORD,IREC)
C
       CALL CORE(RECORD,128)
       READ(3,50)IREC
       IF(IREC.EQ.7) CALL POSFLD(UNIT,IPOS,RECORD,IREC)
       WRITE(6,55)
55     FORMAT('END OF THE FIELD/POSITION DATA FOR THE DESIRED STREET')
C
60     CALL CORE(RECORD,128)
       READ(3,50)IREC
       IF(IREC.EQ.99) GO TO 80
       WRITE(6,65)STN
65     FORMAT('MORE DATA NEEDED FOR STATION',2X,A7,2X,'(YES OR NO) ?')
       READ(9,70) ANSWER
70     FORMAT(3A1)
       IF(EQUAL(ANSWER,YES,3))GO TO 75
       IF(EQUAL(ANSWER,NO,3)) GO TO 90
75     GO TO 10
C  IF MORE DATA NOT NEEDED FOR STATION, CLOSE AND NAME FILE
C
80     WRITE(6,85)IREC
85     FORMAT('NO MORE DATA AVAILABLE FROM TAPE;IREC =',2X,I2)
90     WRITE(6,95) STN
95     FORMAT('END OF DATA FOR STATION:',2X,A7)
```

```
      CALL SETINF(0,0,0,0,'PRIV.')
      CALL CLSFIL(UNIT,K,'RLSE RENAME.',STN)
      CALL FILMSG(K,UNIT)
C
C  IF DATA IS REQUIRED FOR OTHER STATIONS, REWIND TAPE AND REPEAT
C  DATA SEARCH AND CREATE A NEW FILE FOR EACH NEW STATION. IF NO
C  FURTHER DATA IS REQUIRED, STOP EXECUTION.
C
      WRITE(6,100)
100   FORMAT('DATA REQUIRED FOR ANY OTHER STATIONS?')
      READ(9,70) ANSWER
      IF(EQUAL(ANSWER,YES,3)) GO TO 2
      IF(EQUAL(ANSWER,NO,3)) GO TO 105
105   STOP
      END
      SUBROUTINE STDAT(UNIT,RECORD,IREC)
C
C THE FOLLOWING SUBROUTINE SEARCHES FOR THE DESIRED STREET OF TRAVEL
C AS WELL AS THE DESIRED INTERSECTING STREET.
C
C****************** RECORD TYPE 6 ON DOCFM.BOB FILE *****************
C************************* SUBROUTINE STDAT ****************************
C
      LOGICAL*1  TRAVST(24),P(24),Q(24),INTST(24),EQUAL
      INTEGER UNIT,IREC
      LOGICAL*1 RECORD(128)
C
      WRITE(6,110)
110   FORMAT('ENTER THE DESIRED STREET OF TRAVEL (=TRAVST):')
      READ(9,115) TRAVST
115   FORMAT(24A1)
      WRITE(6,120)
120   FORMAT('ENTER THE DESIRED INTERSECTING STREET (=INTST):')
      READ(9,115) INTST
125   WRITE(6,130) RECORD
130   FORMAT(128A1)
135   CALL CORE(RECORD,128)
      READ(3,140) P,Q
140   FORMAT(28X,24A1,24A1)
      IF(EQUAL(P,TRAVST,24)) GO TO 155
145   READ(3,130) RECORD
      CALL CORE(RECORD,128)
      READ(3,150) IREC
150   FORMAT(1X,I2)
      IF(IREC.NE.6) GO TO 145
      GO TO 125
155   IF(EQUAL(Q,INTST,24)) GO TO 160
      GO TO 145
160   WRITE(6,165)
165   FORMAT('THE DESIRED STREETS HAVE BEEN FOUND')
      WRITE(UNIT,170) P
      WRITE(6,170) P
170   FORMAT('STREET:',2X,24A1)
      WRITE(UNIT,175) Q
      WRITE(6,175) Q
```

```
175     FORMAT('INTERSECTING STREET:',2X,24A1)
        READ(3,130) RECORD
        RETURN
        END
        SUBROUTINE POSFLD(UNIT,IPOS,RECORD,IVAL)
C
C   THE FOLLOWING SUBROUTINE RECORDS THE ELECTRIC FIELD STRENGTH
C   (DBU ABOVE 1 MICROVOLT) VERSUS POSITION (IN KILOMETRES) ALONG
C   THE STREET ON WHICH WE ARE TRAVELLING.  THE POSITION VERSUS
C   FIELD DATA WILL BE SENT TO AN OUTPUT FILE FOR STORAGE.
C
C************* RECORD TYPES 7 AND 17 IN BOB.DOC FILE **************
C*************************** SUBROUTINE POSFLD ***********************
C
        REAL BPOS,EPOS,AV,AFLD,BFLD,CFLD,DFLD
        INTEGER IVAL,IPOS,UNIT,FLD(20)
        LOGICAL*1 RECORD(128)
C
        WRITE(UNIT,490)
490     FORMAT('POSITION(KM)',2X,'FIELD(DBUV/M)',1X,'FIELD(V/M)',2X,'FIEL
      *D(W/M**2)',2X,'FIELD(MW/CM**2)')
500     CALL CORE(RECORD,128)
        READ(3,510) BPOS, EPOS
510     FORMAT(20X,F7.5,11X,F7.5)
        AV = (BPOS + EPOS)/2.0
        IF(IPOS.GT.20) GO TO 600
        CALL CORE(RECORD,128)
        READ(3,520) (FLD(I),I=1,20)
520     FORMAT(45X,20I4)
C   SCALE FIELD DATA TO:  DBUV/M,V/M,WATTS/M**2,MW/CM**2
        AFLD = FLD(IPOS)/10.0
        BFLD = (10.0**(AFLD/20.0))/(10.0**6.0)
        CFLD = (BFLD**2.0)/377.0
        DFLD = CFLD/10.0
C   SKIP TO NEXT RECORD OF TYPE 7
        READ(3,530) IVAL
530     FORMAT(1X,I2)
        READ(3,540) RECORD
540     FORMAT(128A1)
        WRITE(UNIT,550) AV,AFLD,BFLD,CFLD,DFLD
550     FORMAT(5X,F7.5,6X,F6.1,7X,F5.3,6X,E9.3,6X,E9.3)
C    SKIP TO NEXT RECORD OF TYPE 7 OR 17 DEPENDING ON STATION
590     CALL CORE(RECORD,128)
        READ(3,530) IVAL
        IF((IVAL.EQ.6).OR.(IVAL.EQ.99)) GO TO 700
        GO TO 500
600     CALL FLDCON(UNIT,IPOS,RECORD,AV)
        GO TO 590
700     RETURN
        END
        SUBROUTINE FLDCON(UNIT,IPOS,RECORD,AV)
C
C**************************************************************
C
C   RECORD TYPR 17 IS BEING READ FOR FIELD VALUES ONLY; POSITION
```

```
C  VALUES ARE TAKEN FROM PREVIOIUS RECORD (TYPE 7)
C
C************** RECORD TYPE 17 IN BOB.DOC FILE*****************
C                          SUBROUTINE FLDCON
C
C**************************************************************
      INTEGER FIELD(20),IPOS,UNIT
      LOGICAL*1 RECORD(128)
      REAL AV,PFLD,QFLD,RFLD,SFLD
C
      IPOS = IPOS - 20
      READ(3,71) RECORD
      CALL CORE(RECORD,128)
      READ(3,72) (FIELD(I), I=1,20)
      READ(3,71) RECORD
71    FORMAT(128A1)
72    FORMAT(9X,20I4)
      PFLD = FIELD(IPOS)/10.0
      QFLD = (10.**(PFLD/20.))/(1000000.)
      RFLD = (QFLD**2.)/377.0
      SFLD = RFLD/10.
      WRITE(UNIT,99) AV,PFLD,QFLD,RFLD,SFLD
99    FORMAT(5X,F7.5,6X,F6.1,7X,F5.3,6X,E9.3,6X,E9.3)
      IPOS = IPOS + 20
      RETURN
      END
```

```
C*************************************************************
C               FILE:      DOC.STAT
C               DATE:      MARCH  1984
C               WRITTEN BY:     T.BANIK
C
C-------------------------------------------------------------
C
C
C PROGRAM TO COMPUTE THE MEAN, STANDARD DEVIATION OF A
C SET OF DATA ALONG A GIVEN STREET, AND FOR A PARTICULAR
C STATION.  THE DATA ARE STORED IN MUSIC SAVE FILES. THE MUSIC
C SAVE FILES WERE CREATED BY EXECUTION OF BOB.MAIN WHICH
C USES  FIELD STRENGTH VERSUS POSITION DATA.
C*************************************************************
C
       LOGICAL*1    TITLE(70), LINE1(70), LINE2(70), LINE3(70)
       LOGICAL*1    LINE4(70), GARB(1)
       REAL         YFLD(1318), AVLOG, STDLOG, AVG,STDEV
C
C
C
        READ(5,70) TITLE
        READ(5,70) LINE1
        READ(5,70) LINE2
        READ(5,70) LINE3
        READ(5,70) LINE4
        READ(5,70) GARB
        WRITE(6,70) TITLE
        WRITE(6,70) LINE1
        WRITE(6,70) LINE2
        WRITE(6,70) LINE3
        WRITE(6,70) LINE4
C
70      FORMAT(70A1)
C
C
        NUM = 1
100     READ(5,1,END=200) YFLD(NUM)
1       FORMAT(31X,F5.3)
        NUM = NUM + 1
        GO TO 100
200     NUM = NUM - 1
        WRITE(6,2) NUM
2       FORMAT(2X,I5,1X,'DATA POINTS WERE READ')
        YSUM = 0.
        DO 50 I = 1, NUM
           YSUM = YSUM + YFLD(I)
50      CONTINUE
           AVG = YSUM/NUM
C          WRITE(6,*) YSUM, AVG,NUM
        ASUM = 0.
        DO 60 I = 1, NUM
           A = YFLD(I) -  AVG
           AA = A*A
           ASUM = ASUM + AA
```

```
60        CONTINUE
             VAR = ASUM/(NUM - 1)
             STDEV = SQRT(VAR)
C            WRITE(6,*) STDEV
             AVLOG  = ALOG10(AVG)
             STDLOG = ALOG10(STDEV)
C            WRITE(6,*) AVLOG,STDLOG
             AVLOG = 20.*AVLOG + 120.
             STDLOG = 20.*STDLOG + 120.
           WRITE(6,78) NUM
           WRITE(6,80)  AVLOG
           WRITE(6,85)  STDLOG
78         FORMAT('-',5X,'NUMBER OF DATA POINTS:',2X,I6)
80         FORMAT('-',5X,'MEAN FIELD STRENGTH (DBUV/M):',2X,F8.2)
85         FORMAT('-',5X,'STANDARD DEVIATION (DB):',2X,F8.3)
C
          STOP
          END
/DATA
/INC CITE.HF
```

```
C *************************************************************
C          FILE:      DOC.PLOT
C          DATE:      MARCH 1984
C          WRITTEN BY:  T.BANIK
C-------------------------------------------------------------
C     THIS PROGRAM READS DATA FROM MUSIC SAVE FILES AND
C  PLOTS THIS DATA USING MCGILL MUSIC GRAPHICS SUBROUTINES.
C  THE DATA FILES TO BE PLOTTED WERE CREATED BY THE REPEATED
C  EXECUTION OF FILE 'BOB.MAIN'; THIS LATTER FILE READS DESIRED
C  FIELD VS. POSTION VALUES FROM DATA FILES (MCGILL.AFT,BOB.DOC)
C  WHICH CONTAIN THE MEASURED ELECTROMAGNETIC FIELD VS. POSITION
C  DATA FROM THE RADIO/TV TRANSMITTERS IN THE MONTREAL AREA. THUS,
C  EACH SET OF FIELD DATA CORRESPONDS TO A PARTICULAR (TRANSMITTING)
C  STATION ALONG A GIVEN STREET FOR WHICH THE FIELD VALUES HAVE
C  BEEN RECORDED.
C *************************************************************
      LOGICAL*1 TITLE(70),LINE1(70),LINE2(70),LINE3(70),LINE4(70)
      LOGICAL*1 GARB(70)
      INTEGER NUM
      REAL XPOS(42),YFLD(42),QFLD(42),RFLD(42)
C     REAL XPOS(1500),YFLD(1500),QFLD(1500),RFLD(1500)
      REAL FVX,DVX,FVY,DVY,FVR,DVR,FVQ,DVQ
C
      READ(5,70) TITLE
      READ(5,70) LINE1
      READ(5,70) LINE2
      READ(5,70) LINE3
      READ(5,70) LINE4
      READ(5,70) GARB
      WRITE(6,70) TITLE
      WRITE(6,70) LINE1
      WRITE(6,70) LINE2
      WRITE(6,70) LINE3
      WRITE(6,70) LINE4
      WRITE(6,70) GARB
70    FORMAT(70A1)
C  GET POSITON VS FIELD DATA FROM MUSIC SAVE FILE
      DO 200 NUM=1,40
      READ(5,1) XPOS(NUM),YFLD(NUM),QFLD(NUM),RFLD(NUM)
      XPOS(NUM) = 1000.*XPOS(NUM)
C     WRITE(6,*) XPOS(NUM),YFLD(NUM)
1     FORMAT(5X,F7.5,6X,F6.1,7X,F5.3,6X,E9.3)
C     NUM = NUM + 1
C     GO TO 100
C200   NUM=NUM-1
200   CONTINUE
      WRITE(6,2) NUM
2     FORMAT(2X,I5,1X,'DATA POINTS HAVE BEEN READ')
      CALL PLOTON
C     SCALE DATA TO FIT THE AXES
      CALL SCALE(YFLD,7.0,NUM,1)
      CALL SCALE(QFLD,7.0,NUM,1)
      CALL SCALE(RFLD,7.0,NUM,1)
      XPOS(NUM+1) = 0.0
      XPOS(NUM+2) = 2.5
```

```
      FVY = YFLD(NUM+1)
      DVY = YFLD(NUM+2)
      FVQ = QFLD(NUM+1)
      DVQ = QFLD(NUM+2)
      FVR = RFLD(NUM+1)
      DVR = RFLD(NUM+2)
      CALL PLOT(1.0,0.5,-3)
      CALL AXS(0.,0.,'POSITION (M)',-12,10.,0.,0.0,2.5,1,0.,1.0)
      CALL AXS(0.,0.,'FIELD STRENGTH (DBUV/M)',23,7.0,90.,FVY,DVY,1,0.,
     $ 1.0)
C
C
C
C   PUT TITLE AND OTHER INFORMATION ON GRAPH
C
C     CALL SYMBOL(0.0,8.5,.3,TITLE,0.,35)
C     CALL D6SYMB(0.0,8.5,.28,TITLE,0.,35)
C     CALL SYMBOL(3.0,8.1,.1,LINE1,0.,60)
C     CALL D6SYMB(3.0,8.1,.14,LINE1,0.,60)
C     CALL SYMBOL(3.0,7.8,.1,LINE2,0.,60)
C     CALL D6SYMB(3.0,7.8,.14,LINE2,0.,60)
C     CALL SYMBOL(3.0,7.5,.1,LINE3,0.,60)
C     CALL D6SYMB(3.0,7.5,.14,LINE3,0.,60)
C     CALL SYMBOL(3.0,7.2,.1,LINE4,0.,60)
C     CALL D6SYMB(3.0,7.2,.14,LINE4,0.,60)
C     CALL ZSPEED(85)
      CALL FLINE(XPOS,YFLD,-NUM,1,1,1)
      CALL ENDPLT
      STOP
      END
/INC DMP6.OBJ
/DATA
/INC CITE.HF
```

APPENDIX (B):
AM/FM/TV TRANSMITTER DATA AND RADIATION PATTERNS

AM/FM/TV TRANSMITTER DATA

CITY: MONTREAL BAND: AM (540 - 1580 kHz)

AM TRANSMITTER DATA

11:21 MA 12 '83 LT01#AA0965/MOAMTD.RRC0070

STN	f(kHz)	kW		LAT.			LONG.			
CFCF	600	05.000	D	45	23	34	73	41	55	D'-1
CBF	690	50.000		45	25	42	73	26	58	ND
CKAC	730	50.000		45	30	50	73	58	26	DA-1
CJAD	800	50.000	D	45	14	50	73	31	25	DA-2
CKVL	850	50.000	D	45	23	32	73	35	16	DA-2
CBM	940	50.000		45	25	42	73	26	58	DA-1
CKGM	980	10.000		45	22	05	73	37	23	DA-2
CHRS	1090	10.000		45	19	17	73	13	36	ND
CJMS	1280	50.000		45	19	31	73	32	55	DA-2
CFMB	1410	10.000		45	24	10	73	24	52	DA-1
CKO	1470	50.000		45	20	03	73	35	35	DA-1
CXLM	1570	50.000		45	35	49	73	45	39	DA-2

CITY: MONTREAL BAND: FM (88 - 108 MHz) ; TV

FM/TV TRANSMITTER DATA

11:21 MAY 12 '83 LT01#AA0965/MOFTTD.RRC0070

STATION	f(kHz)	kW	LAT.			LONG.				h_1(m)				
CBFT	55250	100.	45	30	20	73	35	32	10.	278.	16.4	.01	.21	0.0
CBMT	83250	100.	45	30	20	73	35	32	15.	252.	6.1	.07	.25	0.0
CFQR	92500	41.4	45	30	20	73	35	32		298.	14.0	.01	.24	0.0
CBMFM	93500	24.6	45	30	20	73	35	32		251.	6.1	.07	.25	0.0
CKMF	94300	41.4	45	30	20	73	35	32		298.	14.0	.01	.22	0.0
CJFM	95900	41.2	45	30	20	73	35	32		298.	14.0	.20	.25	0.0
CKOI	96900	307.	45	29	54	73	54	16		217.	14.0	.20	.25	0.0
CHOM	97700	41.2	45	30	20	73	35	32		298.	14.0	.20	.25	0.0
CBFFM	100700	100.	45	30	20	73	35	32		251.	6.1	.07	.25	0.0
CINQ	102300	.04	45	31	04	73	34	48		46.	30.0	.01	.48	0.0
CFGL	105700	100.	45	38	58	73	42	53		121.	4.7	.01	.22	0.0
CITE	107300	100.	45	31	06	73	34	04		112.	7.5	.1	.22	0.0
CFTM	193250	325.	45	30	20	73	35	32	160.	296.	4.0	.20	.24	0.0
CFCFTV	205250	325.	45	30	20	73	35	32	160.	296.	6.0	.21	.24	0.0
CIVM	489250	1212.	45	30	20	73	35	32	242.	191.	3.1	.22	.15	0.5

DIRECTIONAL ANTENNA DESCRIPTION SHEET

STATION	: CBM	MAIN STUDIO:	Montreal, Que.
POWER	: 50 kw	FREQUENCY :	940 KHz, Class I-B
NOTIFICATION LIST NOS:	372	DATE :	April 7, 1978
GEOGRAPHICAL LOCATION:	North Latitude:	45°25'42"	
	West Longitude:	73°26'58"	

ANTENNA CHARACTERISTICS

MODE OF OPERATION : DA-1

NUMBER OF ELEMENTS : Two (2)

TYPE OF ELEMENTS : No. 1 - Uniform cross-section, guyed steel tower, base insulated for series feed

No. 2 - Uniform cross-section, guyed steel tower, base insulated for series feed, no top-loading

TOWERS	: No. 1	No. 2
Height above insulators of radiating elements:	357' (123°)	580' (199.5°)
Overall height of radiating elements :	367'	585'
Field ratios :	0.12	1.0
Phasing :	-90°	0°
Spacing :	111.3° (323.5')	0°
Orientation :	23°	Ref.

July 9, 1974
Rev. 3.22.6.76

...ii

GROUND SYSTEM : 120 equally spaced radials of 1" wide copper strap, buried approximately 8" deep, 600 ft. long except those bonded along the common cord between the towers and those limited by property size; plus a solid 40' x 40' sheet at the base of each tower.

PREDICTED EFFECTIVE FIELD: 1830 mV/m at 1 mile for 50 kW
258.8 mV/m at 1 mile for 1 kW

July 9, 1974
Rev. 1
Rev. 2 (16.12.74)
Rev. 3 (22.06.76)
Rev. 4 (13.03.78)

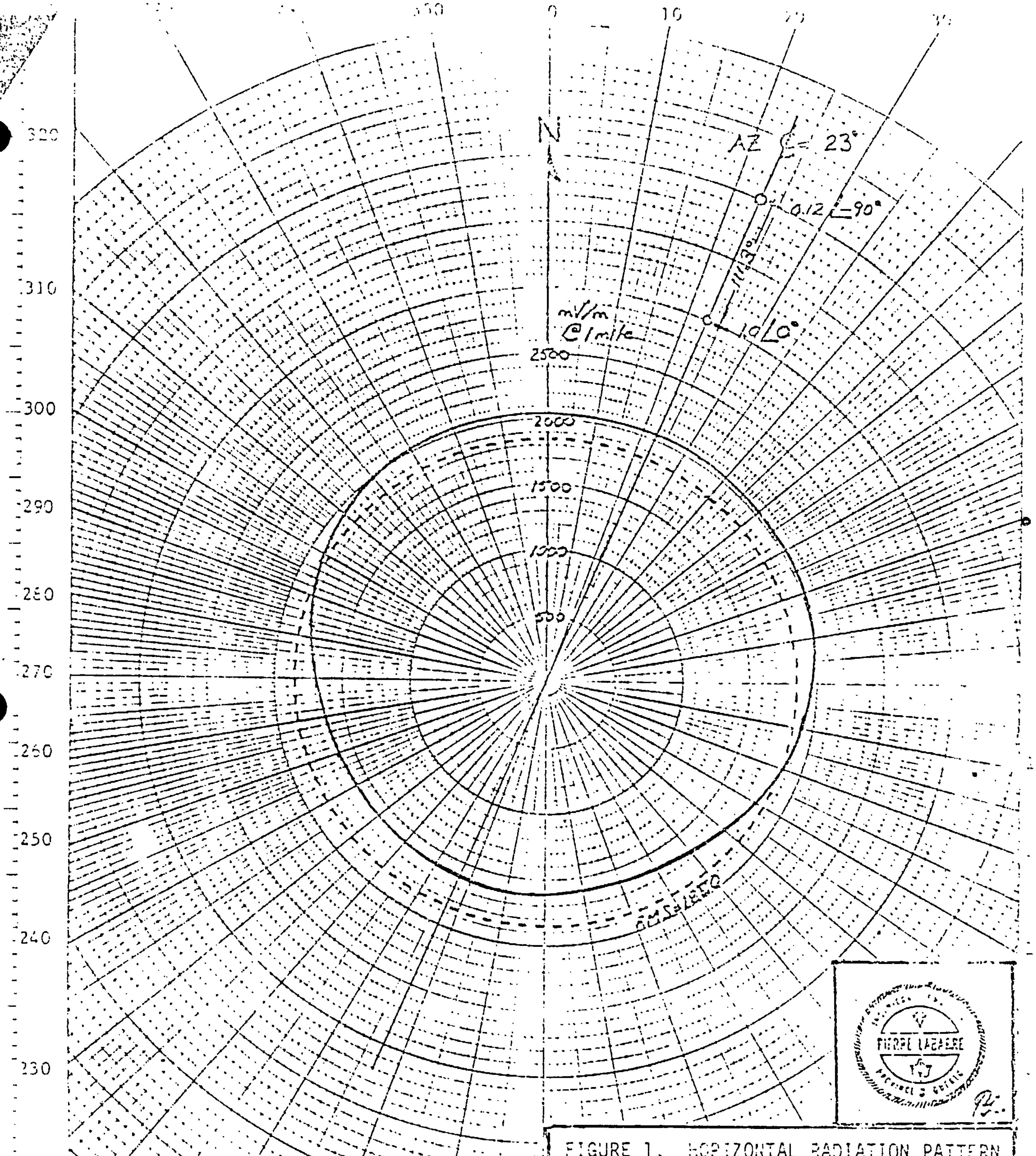


FIGURE 1. HORIZONTAL RADIATION PATTERN

Rev. 2
Rev. 3 CHANGE IN LOCATION
(2.6.76) CBM - MONTREAL, QUE.

Class I-B, 50 KW, DA-1, 940 KHz

PROJECT 2101 Pierre Labarre, Eng.
July 8, 197 St. Lambert, Que.

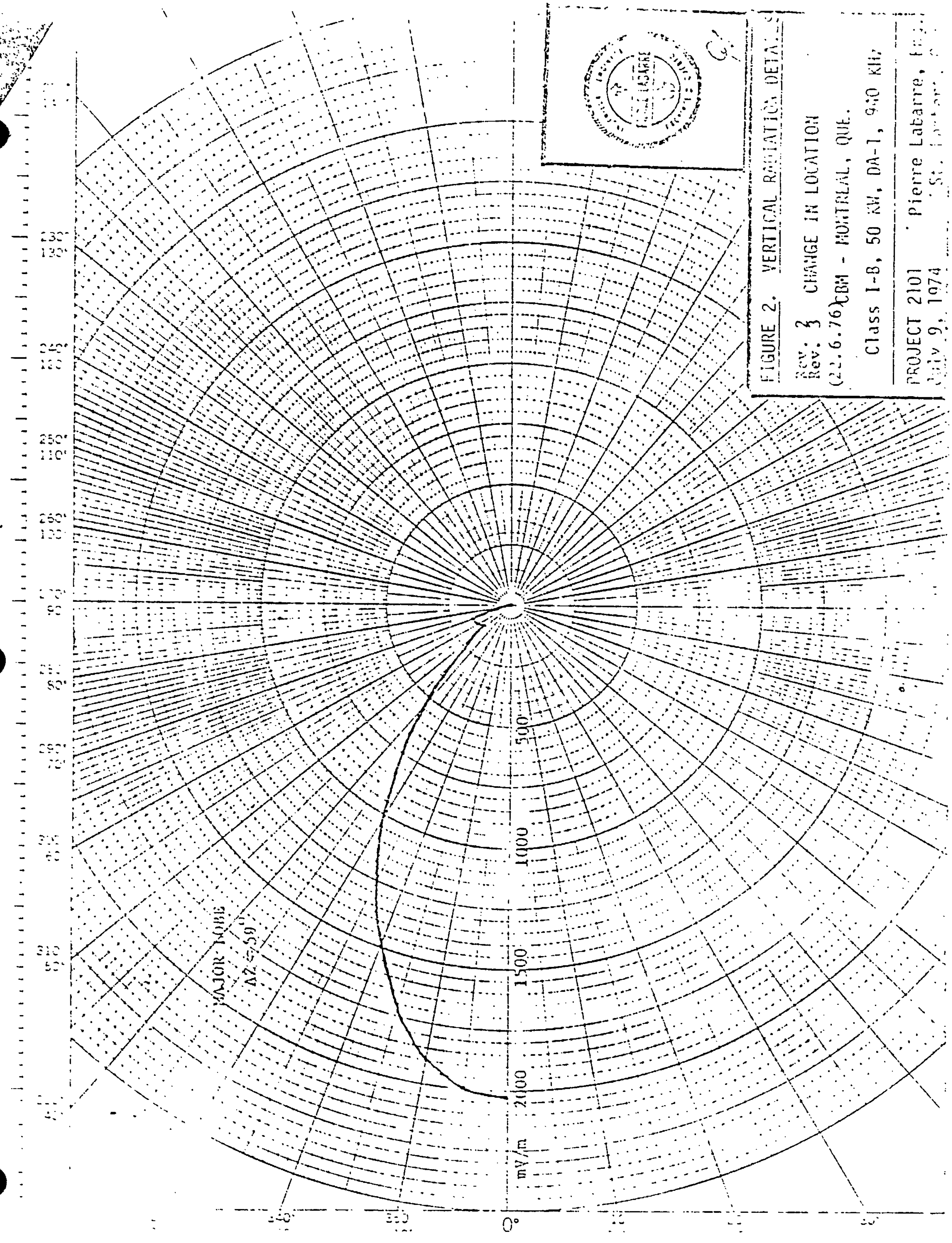


FIGURE 2. VERTICAL RADIATION DETAIL
Rev. 2
Rev. 3 CHANGE IN LOCATION
(22.6.76) CBM - MONTREAL, QUE.
Class I-B, 50 KW, DA-1, 940 KHz
PROJECT 2101
July 9, 1974
Pierre Labarre
MAJOR LOBE
AZ = 59°
500
1000
1500
2000
mV/m
0°

CIVM - UHF-TV

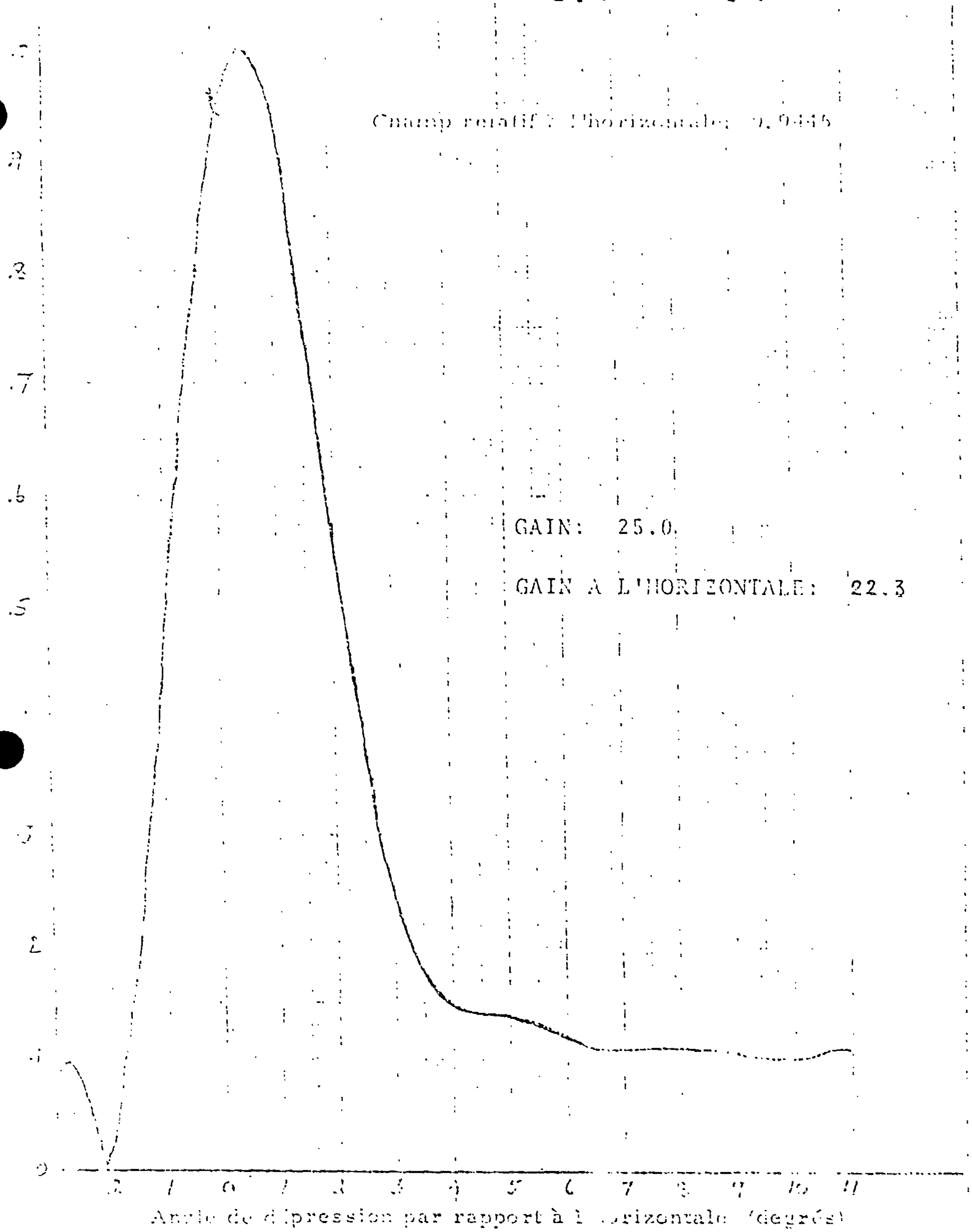
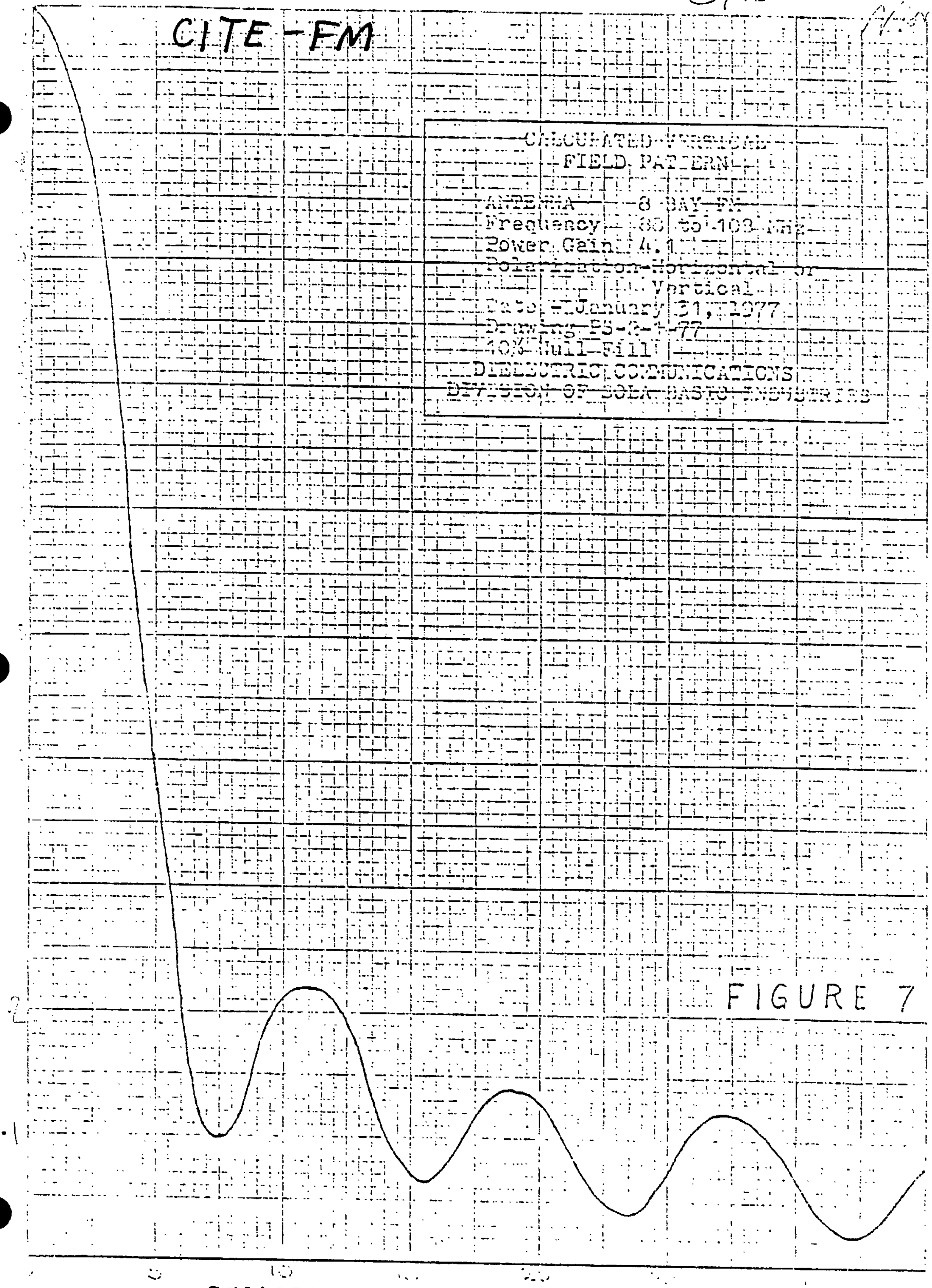


DIAGRAMME DU RAYONNEMENT VERTICAL DE L'ANTENNE
... de Télévision, Montréal, Qué. Projet 9.1

video (hor.
audio (hor.
et 983
direction,
beam tilt,



CITE-FM
FIELD PATTERN
Frequency
Power Gain 4.1
Vertical
January 31, 1977
DIELECTRIC COMMUNICATIONS
.2
.1
5
10
20

FIGURE 7

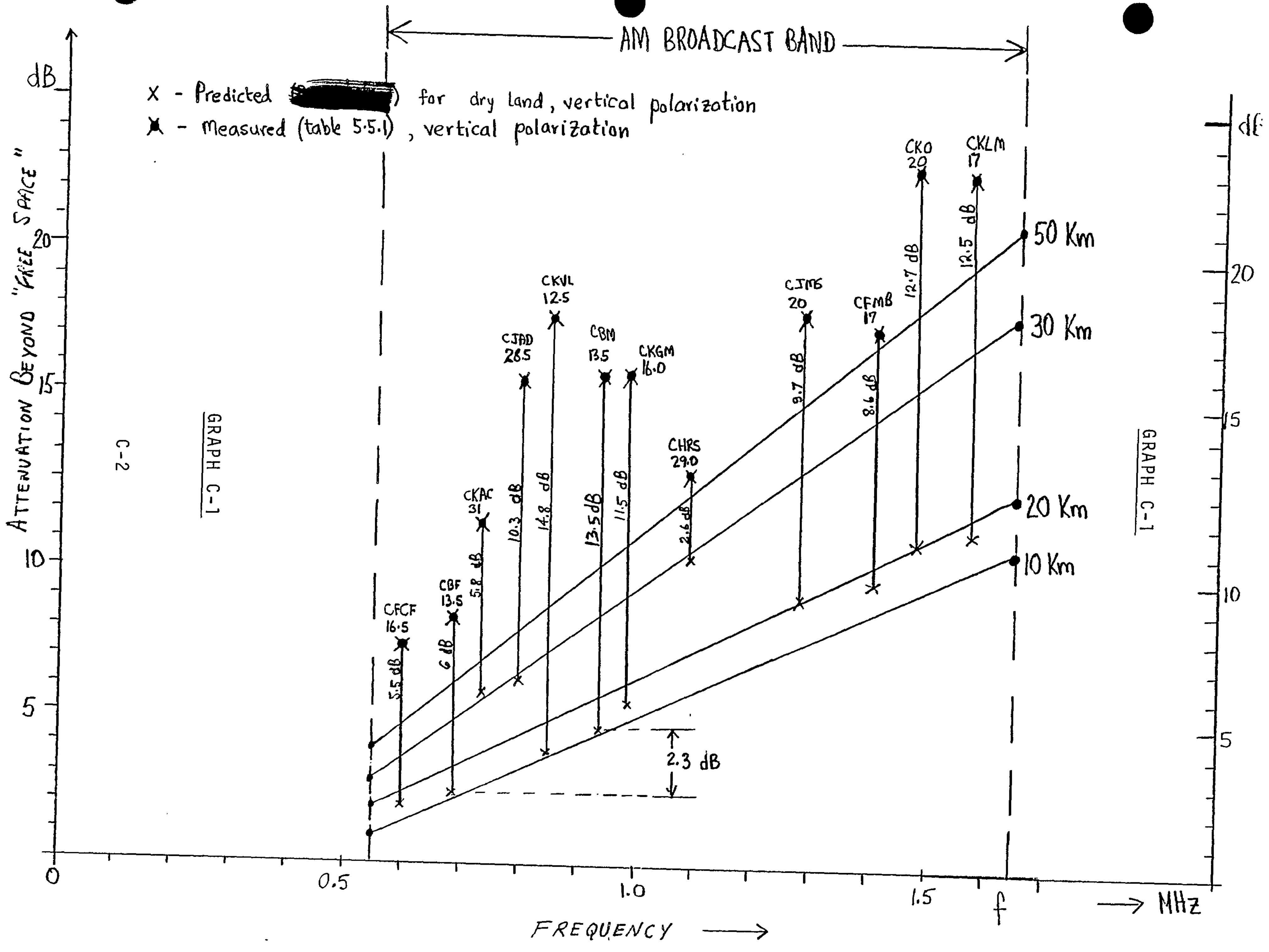
APPENDIX "C"

AM FIELD STRENGTHS

This appendix addresses the phenomenon of the striking difference in field strength between stations CBF (690 kHz) and CBM (940 kHz). The CBF measured field strength is 98.2 dBuV/m and that of CBM is 91.2 dBuV/m, a difference of 7.0 dB. Furthermore, CBF is the strongest AM station of all the AM stations at the measured location. The interesting feature of CBF and CBM stations is that they are geographically collocated, that they share the same antenna towers, that they have identical input power and that their patterns are essentially omnidirectional, with CBM having slight directionality, showing a 1.5% stronger signal in the direction of the site of measurement.

In order to explain possible reasons for this difference a more detailed propagation model was examined. This model is derived from propagation formulae and charts contained in David and Voge, "Propagation of Waves", Pergamon Press (1969), pages 73 - 83, copies of which are at the end of this Appendix.

In particular, attention is drawn to Fig. 4.13 (page (C-7)) which shows attenuation curves over land (fertile soil), at different wavelengths, for vertical polarization, as a function of disatnce.



AM BROADCAST BAND
X - Predicted [redacted]) for dry land, vertical polarization
X - Measured (table 5.5.1), vertical polarization
dB
ATTENUATION BEYOND "FREE SPACE"
FREQUENCY
MHz
0
0.5
1.0
1.5
f
5
10
15
20
50 Km
30 Km
20 Km
10 Km
CFCF 16.5
5.5 dB
CBF 13.5
6 dB
CKAC 31
5.8 dB
CJAD 28.5
10.3 dB
CKVL 12.5
14.8 dB
CBM 13.5
13.5 dB
CKGM 16.0
11.5 dB
CHRS 29.0
2.6 dB
CJMS 20
9.7 dB
CFMB 17
8.6 dB
CKO 20
12.7 dB
CKLM 17
12.5 dB
2.3 dB
GRAPH C-1
C-2
GRAPH C-1

Figure 4.13 of David and Voge has been transformed and replotted in graph C-1 (page C-2), showing the additional attenuation beyond "free space" 1/R loss only, as a function of frequency. A family of curves is shown, each one for a different transmitter to receiving site distance.

Superposed on these curves, shown by X, are the extra attenuation values for all AM stations measured, as predicted by the David and Voge propagation model. In addition, indicated by ✖ are the values obtained from the actual measurements.

Certain notable features are evident:

1. The general trend, in all cases, is that greater attenuation is to be expected with increasing frequency;

2. In all cases the measured values of attenuation are considerably higher than those predicted by Fig. 4.13 and the transformed curves. Since the Fig. 4.13 values are predicted for a <u>smooth</u> <u>land</u> surface without building clutter, the additional attenuation is not surprising;

3. In the particular case of CBF and CBM, in whose case the attenuation differs by approximately 7.5 dB, the smooth land surface prediction should differ by about 2.5 dB because of the <u>DIFFERENCE</u> <u>IN</u> <u>FREQUENCY</u>.

There remains therefore an additional 5 dB attenuation in the case of CBM which is not attributable to frequency difference. This 5 dB difference remains unexplained, but it may be speculated that the varying effects of the built-up city ground clutter may influence the signals in a frequency selective manner.

David and Voge:

"Propagation of Waves"

Pergamon Press
1969

<u>Pages 73 - 83</u>

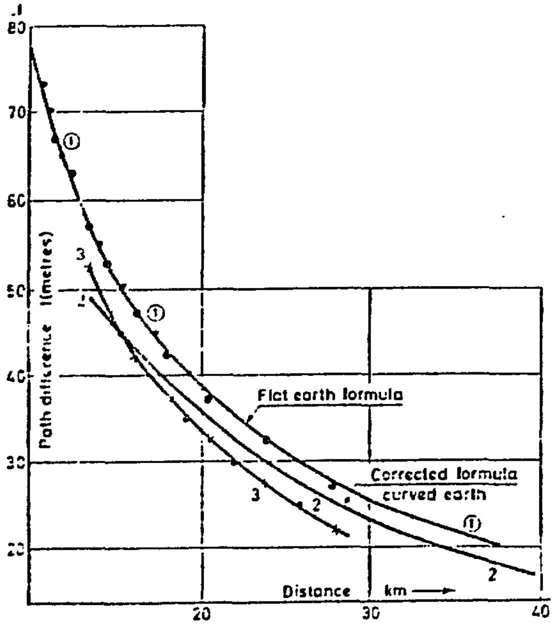


FIG. 4.11b. Comparison of calculated and observed path differences (MAX and min of field) for:

$h_1 = 360$ m; $h_2 = 1060$ m; $\lambda = 5$ m

——— calculated, simple formula, flat Earth

— — — calculated, corrected formula, round Earth, $a = 8500$ km

●.●.● MAX and min observed (assuming that the MAX at 27·5 km is the 6th)

×.×.× MAX and min observed (assuming that the MAX at 27·5 km is the 5th)

4.3.4. Modification of the apparent curvature of the Earth by the shape of the ground

It may happen that in the vicinity of the aerials, or in the Fresnel "reflection zone" (Fig. 3.4), there is some feature of the surface whose general shape produces the effect of a curvature very different from that of the terrestrial sphere: a smaller radius in the case of a hill, a radius of opposite sign in the case of a hollow.

We can then adjust part of the preceding calculation by generalizing the "divergence coefficient D" to include one or two different radii of curvature, possibly negative (in which case there is a convergence effect with $D > 1$). Norton† claims to have greatly improved the agreement between calculated and measured values in this way. Certainly, one can explain the reinforcement in the field which is frequently observed in certain areas where the ground slopes concavely towards the transmitter.

Note. In all problems of visibility, heights with respect to the horizon, effect of obstacles, etc., it is usually convenient to plot graphs with an extended "scale of heights" and curves representing the apparent curvature of the Earth (including refraction) on this scale.

4.4. Diffraction (or "shadow") zone

4.4.1. General

When the heights of the stations are reduced, they reach the tangent plane (Fig. 4.1, T_3R_3), and then pass below it (T_1R_1). The preceding formulae, derived from geometrical optics, which would indicate zero field, now cease to be valid. In fact the waves can, to a certain extent, follow the curvature of the Earth by the phenomenon of *diffraction*. But this is an extremely difficult physical optics phenomenon which requires a complete revision of the method of calculation starting from Maxwell's equations in spherical coordinates with the "limiting condition" that the properties of the medium change at the air-ground surface of separation. The differential equations thus obtained may be integrated by expansion into series; but the large range of variation of the parameters (notably f and σ) and the slow rate of convergence of the series make the solution extremely laborious.

The efforts of numerous eminent mathematicians—Sommerfeld, H. Poincaré, Watson, Laporte, Eckersley, Van der Pol and

† Norton, *Trans. I.R.E. Professional Group on Antennas and Propagation*, PGAP. 3, Aug. 1952, p. 152 (166) and C.C.I.R. London, 1953, doc. 11.

Bremmer, Burrows, Norton, etc.—and innumerable international commissions have failed to produce a general formula which can be used by engineers. One therefore has to subdivide the problem into various categories, use for each one graphs prepared in advance and interpolate, sometimes quite arbitrarily, in intermediate categories.

We start with the simplifying assumptions that the heights h_1, h_2 of the stations are fixed and chosen in advance to simplify the solution; the chosen value is nearly always zero, i.e. the stations are assumed to be at ground level. In exceptional cases, we can also take for this value a certain "natural unit", a function of the wavelength.†

Once this part of the problem has been solved, we next study the effect of the heights. As long as they are low (below a certain "critical" value), the effect is purely "local" and may be likened either to a reduction in the range or a supplementary gain multiplying the ground-level field. There are special graphs for taking account of this.

Finally, if the heights are markedly greater than the "critical" value and almost up to the point at which direct visibility is possible, the problem acquires maximum complexity. Only a few particular cases have been treated (for example, that where one station is very high and the other is near the ground); in this zone, known as the *intermediate zone*, one is often reduced to interpolating between the values for the *interference zone* and those for the *shadow zone*.

4.4.2. Stations at ground level

By "ground level" is meant "at a height of less than a wavelength". This is usually the case with long and medium waves, but not with ultrashort waves.

Firstly, it will be recalled that the nearness of the ground considerably modifies the properties of the aerial—the vertical

† Kerr, *Propagation of Short Radio Waves*, Fishback method, chap. 2.

radiation diagram and the effective height—the radiation resistance, etc.

In particular, for a vertical doublet placed on flat ground of infinite conductivity, an "image" is formed in the ground: the field is doubled at equal intensity, but at the expense of doubling the radiation resistance, so that for the same radiated power there is a gain of $\sqrt{2}$ and formula (1.8) becomes

$$E_0\left(\frac{\text{mV}}{\text{m}}\right) = \frac{300\sqrt{W_r\,(\text{kW})}}{d\,(\text{km})}. \tag{4.16}$$

In reality the ground is never of infinite conductivity and the Earth is not flat. The above field therefore has to be multiplied by a supplementary attenuation coefficient A and it decreases with increasing distance at a rate faster than $1/d$, according to a complex law where two effects are superimposed:

1. At *short distances* where the Earth's curvature is unimportant, the attenuation results from an *absorption* of energy by the ground. Calculation shows that the constants of the ground—relative dielectric constant ε_r, conductivity σ (mho/m)—combine with the wavelength λ (m) and the distance d (km) to constitute an overall (complex) parameter which was called by Sommerfeld the *numerical distance*:†

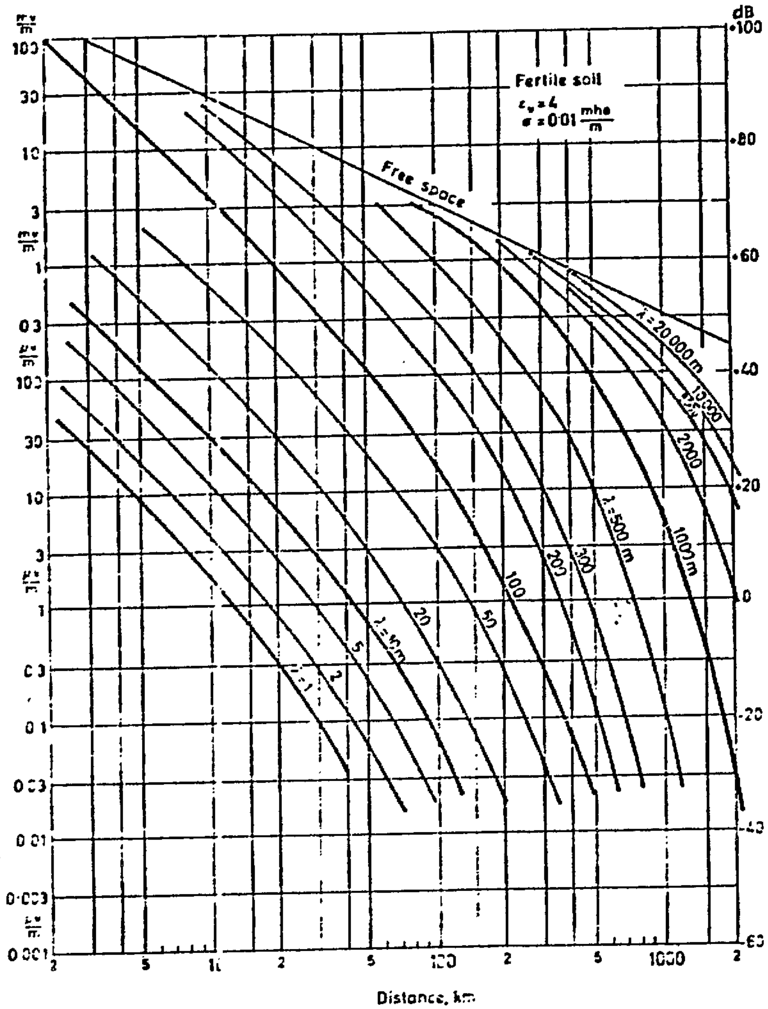
$$p = \frac{\pi \mathcal{C}}{\lambda}\cdot d = \frac{\pi C d}{\lambda}\, e^{-j(\pi/2-\beta)}. \tag{4.17}$$

$\mathcal{C}$ being the complex constant defined in § 3.2.3 (polarization coefficient), a function of the polarization, but used here with $\varphi = 0$, i.e. $\cos^2\varphi = 1$:

$$\mathcal{C}_V = \frac{\eta-1}{\eta^2}, \quad \mathcal{C}_H = \eta - 1.$$

† Some authors (e.g. Burrows) sometimes take twice this value for p. It should be mentioned that Sommerfeld's initial calculation contained several errors which have been the subject of contradictory criticism (see Norton, *Proc. I.R.E.*, Sept. 1937; Eckardt and Kahan, *J. de Phys.*, May 1948; Poincelot, *Ann. Télécomm.*, June 1953; Fannin, *Proc. I.R.E.*, Aug. 1953; Barlow and Cullen, *Proc. I.E.E.*, pt. III, Nov. 1953; and a general historical revue by Boudouris, *Onde Électrique* May 1957). But his work, revised and corrected, is still, nevertheless, the basis for all succeeding efforts; we accord to him here the credit which he deserves.

C-7



[redacted] Field strength for 1 kW radiated. Stations at ground level.
[redacted]

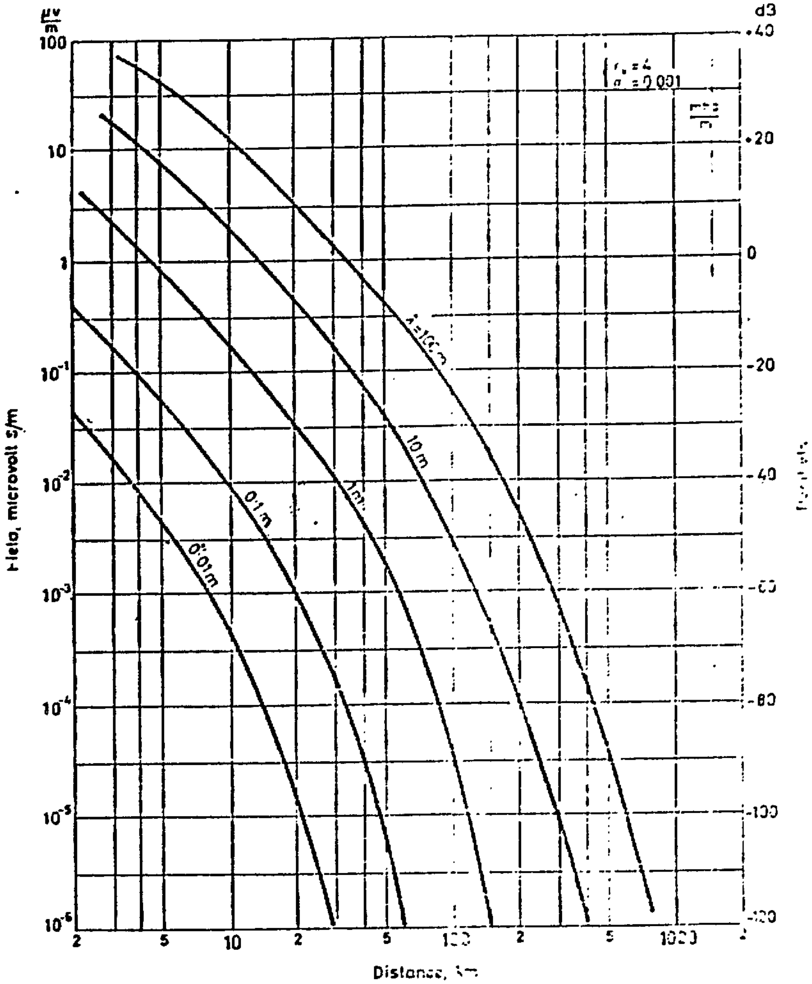


FIG. 4.14. Field strength for 1 kW radiated.
DRY SOIL—*horizontal polarization*

The supplementary attenuation A_1 which multiplies the field E_0 is a function of this parameter p:

$$A_1 = f(p), \tag{4.18}$$

for which the general expression is very complicated and can be written in various forms; for example, that of Sommerfeld-Norton is

$$A = f(p, b)\, e^{jy} = 1 + j\sqrt{p}\cdot e^{-|p|} \times 2\int_{-j\sqrt{p}}^{\infty} e^{-u^2}\, du, \tag{4.18a}$$

[the integral is the "error function" of the variable $(-j\sqrt{p})$].

An approximate expression by Van der Pol is

$$A = \frac{E}{E_0} = \frac{2+0{\cdot}3p}{2+p+0{\cdot}6p^2} \quad \text{when} \quad \varepsilon_r \ll x. \tag{4.18b}$$

(long waves, conductive terrain)

Figure 4.12a, curve 1, is a reproduction of a classical graph giving the value of this attenuation.†

It can be seen that as d increases, A tends to $1/2p$, i.e. is proportional to $1/d$; thus the total attenuation of the field tends to $1/d^2$; it can also be seen that for highly conductive ground and long waves, $60\,c\lambda \gg \varepsilon_r$; therefore $\mathcal{C}_H \gg \mathcal{C}_V$; the "numerical distance" p is therefore much greater with horizontal polarization, i.e. the field is attenuated more rapidly.

2. At "*large distances*", the most important factor is the curvature of the Earth: it may be followed by diffraction up to a point, but beyond that the attenuation becomes extremely rapid, as a function of the essential parameter:

$$\eta = \beta_0 \frac{d}{a^{2/3}\lambda^{1/3}} = \frac{\beta_0}{a^{2/3}} \times d_c. \tag{4.19}$$

The coefficient β_0 depends slightly on the nature of the terrain and on the polarization [i.e. on the coefficient $\mathcal{C}$ of eqn. (4.17)]; it decreases by about half on going from a very short wavelength over a poor surface to a long wavelength over a high-conductivity

†It will be found, to a higher accuracy, elsewhere, e.g. Norton, *Proc. I.R.E.* Dec. 1941, pp. 623–9, or Burrows and Atwood, *Propagation of Radio Waves*, p. 426, Fig. 56 (with double abscissa, $2p$).

surface; the Earth radius a is actually about 6400 km, but this figure can sometimes be increased by about four-thirds to take account of atmospheric refraction (see below, § 5.2); thus the supplementary attenuation is given by a series of exponentials (curve 2, Fig. 4.12a) as a function of the abscissa:

$$d_c = \frac{d\,(\text{km})}{\sqrt[3]{\lambda\,(\text{km})}} \quad \text{("reduced" or "critical" distance).} \tag{4.20}$$

It can be seen that it begins to be appreciable when d_c is greater than about 100, and becomes exponential when the stations disappear into the "shadow zone" created by the Earth's curvature, i.e. for d_c from about 1000 upwards, say (see Table, p. 79). It is sometimes approximated by the simple formula:

$$\frac{0{\cdot}62}{\sqrt[3]{\lambda\,(\text{m})}}\ \text{dB/km}. \tag{4.20a}$$

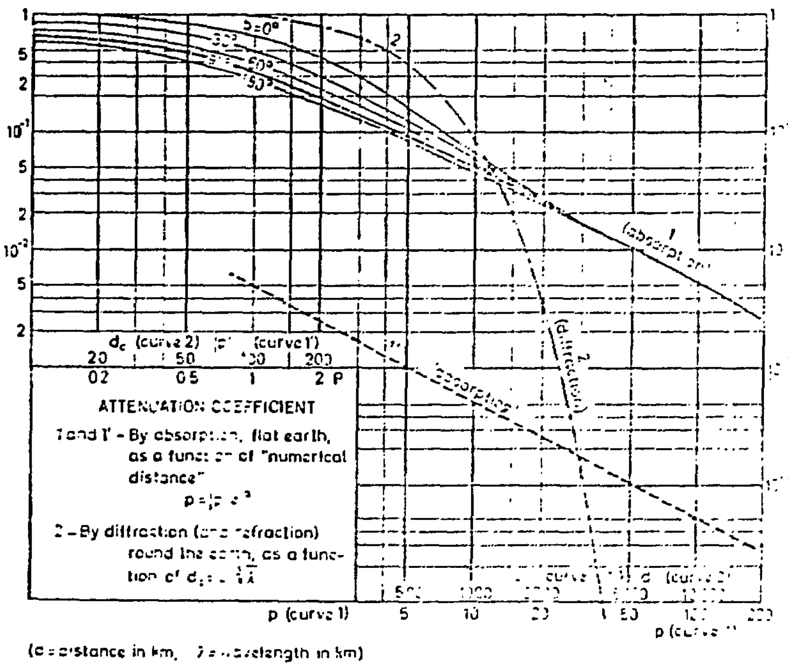


FIG. 4.12a. Theoretical formulae for absorption and diffraction by the Earth.

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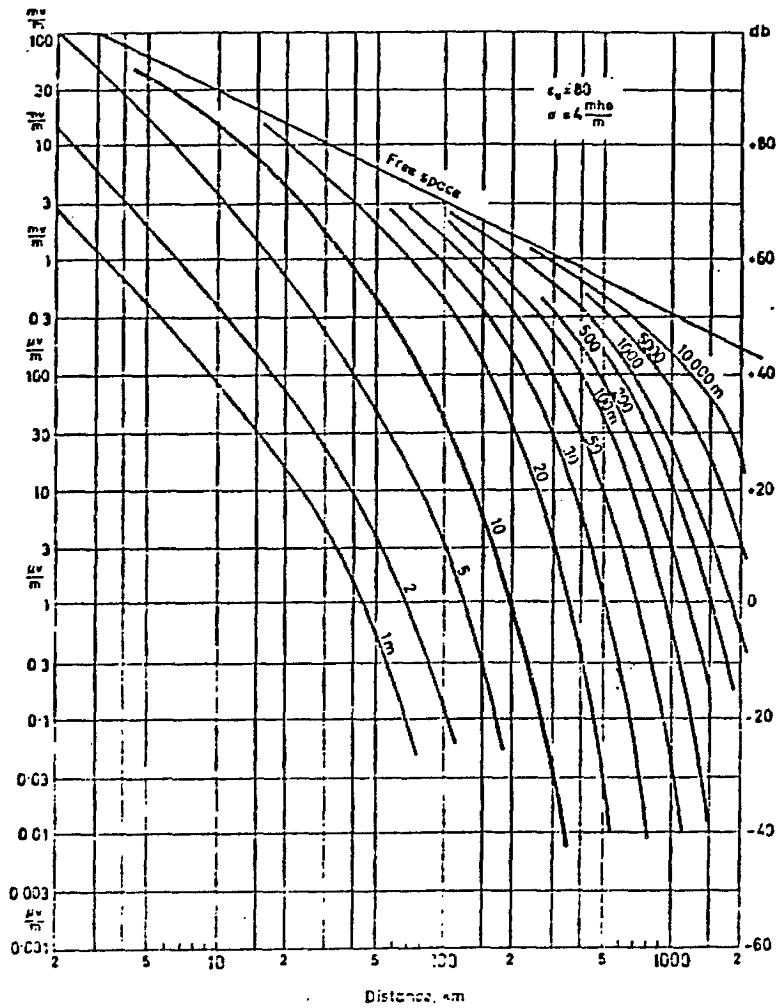

FIG. 4.12b. Field strength for 1 kW radiated. Stations at ground level. SEA—*vertical polarization*

3. In reality, both types of attenuation *(absorption* and *diffraction)* are combined in a complex fashion and the total resultant attenuation is obtained by a series expansion whose terms are tedious to calculate and converge slowly; the numbers against

the curve in Fig. 4.3 are the numbers of terms necessary to obtain an error of less than 1%; some authors think of these terms as distinct "modes" of propagation having a sort of physical existence. In order to facilitate practical applications, we have expressed the results in the form of several graphs prepared in advance for various types of terrain. The wavelength (or frequency) is the parameter for the curves, the abscissa is the distance and the ordinate is the field for a radiated power of 1 kW; if the two scales are logarithmic, the simple law for the decrease of the field in free space according to formula (4.16) is represented by a straight line of slope −1 (depending on the scales) and passing through the point: $x = 10$ km, $y = 30$ mV/m. The curves for the ground wave at various frequencies lie below this line, and the shorter the wavelength and the worse the conductivity of the ground, the lower they lie.

	Values of d for $d_c = 1000$				
λ (km)	10	1	0·1	0·01	0·001
d (km)	2150	1000	470	215	100

Usually, one sticks to *vertical polarization* and to a few typical kinds of terrain: *sea, cultivated land, dry land*; graphs for such cases are shown in Figs. 4.12b and 4.13, in which the curves relating to frequencies less than 30 Mc/s are taken from the most recent official documents;† those relating to higher frequencies are the average of the results of several authors; they are, moreover, of less interest, as we shall see below.

Horizontal polarization is useless at long and medium waves over high-conductivity terrain: the field strength is much too low. It does become usable at metric wavelengths and especially over low-conductivity ground. Figure 4.14 shows the field strength‡ (there is still a marked disadvantage compared with vertical

† C.C.I.R., Los Angeles, 1959.
‡ After Burrows, *loc. cit.*, p. 428.

polarization, but, as we shall see later, this disadvantage rapidly disappears when the height of the stations is increased).

As these graphs are very often used officially, it is essential to understand their value fully: they most certainly represent an excellent approximation for the ground wave alone, i.e. at short distances at any time and at large distances when the indirect ionospheric wave is negligible, i.e. at noon in summer, and as long as the ordinate is not appreciably less than the order of 10 μV/m. However, it must not be forgotten that the constants of the terrain and the atmospheric refraction are always imprecise and therefore there is an uncertainty in the value of the field which gets worse as the distance increases.

Certain international conferences have specified that the actual values lie between a third and three times the predicted values. Others have given various examples of verifications. To quote only one,† regular measurements made at noon on two stations of frequency about 2 Mc's gave the results shown in Table 4.1.

TABLE 4.1

Station measured		LORAN Iceland	Radio ABERDEEN
Distance (over sea)		1130	1474 km
Calculated field strength (ground wave)	ground ray 6500 km	5·2	39 μV/m
	ground ray, increased by four-thirds for refraction	17	62 μV/m
Actual measured field strength (average)		5·5	53

The graphs thus furnish a good indication of the *minimum* range of the transmitters. Note particularly the difference between *land* and *sea* for medium waves: at $\lambda = 200$ m for example, a limiting field of 10 μV/m corresponds to a range of 1000 km

† C.C.I.R., London, 1953, doc. 97.

over sea, and 180 km over cultivated land (it would be 60 km over very dry land).

This difference is less for long and very long waves for which long ranges can be guaranteed over both land and sea, and also for very short waves, which on the other hand suffer a considerable attenuation, even over sea. (But we shall see later that the slightest increase in height greatly modifies this attenuation.) We can now understand the technical motives behind the allocation of frequency bands: wavelengths of 1000–2000 m are much sought after by broadcasting authorities to provide at all times and over all types of terrain a "national" service; whereas, wavelengths of 100–200 m, which are not appropriate to such a service, are still very useful for maritime or coastal services, fishing boats, etc. (see § 8.2).

4.4.3. Propagation over inhomogeneous terrains, especially mixed (land–sea) trajectories

It has been assumed so far that the nature of the ground was the same all the way along the trajectory (ε, σ independent of distance and depth).

It is obvious that this simplification is, in fact, very rare: most of the time, over large distances, the nature of the ground must vary; we have, alternately, ground which is more or less dry, more or less cultivated, more or less hilly, or even with some parts of the trajectory over land and others over sea; this latter case is of particular interest for coastal services or broadcasting in maritime regions interspersed with islands or peninsulas. One can also have stratified ground, i.e. consisting of several layers of different conductivities.

What is the law of propagation of the field in these cases? It is very difficult indeed to calculate.

The only case that can be treated with any precision is the case where a wave, after following a path d_1 over a surface of conductivity σ_1, passes over a surface of conductivity σ_2 and

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