FOR MEMBERS OF WORKING GROUP
ON RE-RADIATION PROBLEMS IN AM
BROADCASTING

INTERIM REPORT NO. 5

THE EFFECTS OF RE-RADIATION

FROM

HIGHRISE BUILDINGS, TRANSMISSION LINES, TOWERS AND OTHER STRUCTURES

UPON AM BROADCASTING DIRECTIONAL ARRAYS

14 February 1979

INTERIM REPORT NO. 5

THE EFFECTS OF RE-RADIATION FROM HIGHRISE BUILDINGS, TRANSMISSION LINES, TOWERS AND OTHER STRUCTURES UPON AM BROADCASTING DIRECTIONAL ARRAYS

(DOC Project No. 4-284-15010)

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21 February 1979
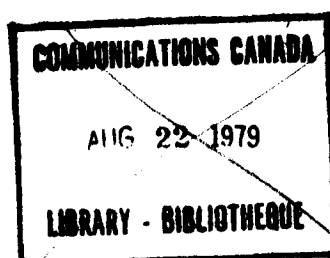
PREFACE

This is the fifth Interim Report describing a research investigation into the effects of highrise buildings, transmission lines, towers and other structures upon the directional pattern of AM broadcast antennas. It describes work that has been carried out during the period 12 October 1978 until 5 February 1979. The report has been prepared for the ninth meeting of the Working Group on Re-Radiation problems in AM Broadcasting scheduled for 12 March 1979.

The last interim report, dated 1 November 1978 included an overview of the project, new results to that date, and two proposals for continuation of the project beyond 31 March 1979: (1) a minimal program for next fiscal year (1979/80); and (2) a proposed more ambitious 3-year program which included a $250K capital expenditure for a new antenna modelling range.

This report has nothing new to say on planning for the 3-year program, on the need for the proposed new antenna pattern range, nor on ways and means of obtaining funds for it.

The engineering design study for the proposed new range has been started but is not yet completed. The new work and or related documentation that has been generated in this reporting period are:

A report by the CBC[1] dated 17 January 1979, which is an intervention to the Energy Resources Conservation Board, Keephills-Ellerslie, Alberta, asks that Board to take into consideration the severe pattern distortion that could affect CHFA (680 kHz) if the planned 500KV transmission lines are built. This documentation makes clear the practical importance of our work, and in my view, strengthens the requirement for getting on with the <u>third phase</u> of our proposed research plan (ref. Interim Report No. 4): that is to investigate ways and means of reducing the effects of re-radiation, particularly re-radiation caused by HV power-lines.

This aspect of the work is of particular interest to CEA (c.f. Attachment 1), which is a memorandum d. 11 October 1978, by D.E. Jones to J.R. Leslie, Manager, Ontario Hydro's Electrical Research Department, and also member of the CEA Research and Development Committee. Also relevant is the recent report by Keung[2].

Finally, the new work to be included in this report is a review of methods to calculate the impedance of monopole antennas by transmission line techniques (Appendix 1); measurements made on a model of the CBL/CJBC Hornby situation (Appendix II); and new progress on employing numerical moment methods to calculate re-radiation from power lines (Appendix III).

REFERENCES

1. *Intervention by the Canadian Broadcasting Corporation Re: Application No. 780363 by Calgary Power Ltd. to the Energy Resources Conservation Board,* Keephills - Ellerslie, Alberta 500KV Transmission Lines 1202L & 1230L, CBC, Edmonton, Alberta, 17 January, 1979.

2. *Model Tests of Re-Radiation of Broadcast Signals - Tests of CBL/CJBC at NRC,* Y. H. Keung, Ontario Hydro, Report No. E79-7-K, 2 February, 1979.

INVESTIGATION OF RERADIATION OF AM RADIO
BROADCAST SIGNALS BY POWER LINES

A Working Group was set up in 1976 by the federal Department of Communications (DofC) to look into the problem of reradiation of AM radio broadcast signals from large buildings, power lines, etc. The Group has representatives from the Canadian Association of Broadcasters, Canadian Association of Broadcast Consultants, CBC, CRTC, DofC and CEA.

The problem that led to the formation of this Group is radiation pattern distortion of AM radio broadcast signals caused by reradiation of the signals by large structures. This results in "filling in" of nulls in highly directional patterns, with consequent signal interference in the service areas of other broadcast stations, as well as "scalloping" of omni-directional patterns with resulting loss in coverage area.

CEA participation was requested because steel-tower transmission lines are one of the sources of such reradiation. Ontario Hydro and Hydro Quebec, for example, are now involved in problems with radio stations along routes of proposed transmission lines. Various "cures" had been tried, but no major investigations had been carried out. For this reason the Working Group organized research projects that might increase understanding of the problem and of practical remedial measures.

The investigation to date has been carried out under the coordination of the Communications Research Center (CRC) of the DofC, with funding provided by DofC, CBC and the Canadian Association of Broadcasters. Model studies at NRC and at the University of Toronto have been carried out and a start has been made at CRC and U of T on a new analytical approach to the problem. The Working Group has monitored the results at several meetings during the past two years. A progress report was issued in May 1978 discussing the results and proposing further work.*

In a problem of this complexity, the work carried out so far must be considered as preliminary. Further model studies, perhaps on a larger scale, and extension of the analysis is required. The CRC is presently seeking funding through the Working Group for a second phase of the investigation.

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* This report is available from Mr. D.E. Jones of Ontario Hydro Research Division.

It has been suggested that CEA might carry out full scale tests on actual power lines of the effects on radiation patterns of such remedial measures as insulation of overhead ground wires and increasing of the RF impedance of power line towers. This might involve addition of some form of "tuned circuit" in the structure of the tower or some way of breaking the tower up into smaller sections at RF frequencies. Remedial measures carried out by radio consultants have shown that this approach to the problem is practical. However, no quantitative information is available. All work to date has been on a "cut and try" basis.

The problem is urgent in Ontario Hydro and either is or will be in other utilities as more power lines are built on the fringes of metropolitan areas where AM broadcast transmitters are usually located. The problem can also occur in rural areas where regulatory authorities fix the route of a proposed power line and this route runs close to an existing radio transmitter. The attached table was prepared as the result of a survey carried out late in 1976. It is known that several more problems have occurred since then or are imminent in Ontario, Quebec and Alberta.

It is suggested that CEA give consideration to funding of studies on this subject as follows:

1. Studies by a power utility of methods of treatment of power line towers to reduce their reradiation capabilities.

2. Assistance in the funding of further analytical and model studies by CRC.

Messrs. D.E. Jones and T.R. Thompson of Ontario Hydro represent CEA on the Working Group and could provide liaison between the investigations at CRC and those of the power utilities.

D.E. Jones
CEA Representative on
DofC Working Group on
Reradiation of Broadcast
Signals

DEJ/MMcP

October 11, 1978

SUMMARY OF PROBLEMS OF RERADIATION OF AM BROADCAST SIGNALS BY POWER LINES

Dec. 1976

Status of Problem — Action by Power Utility	Transmitter Built Near Existing Line			Line Built Near Existing Transmitter					Line Proposed Near Existing Transmitter (Proposed initial action)				
	No Action	Insulate Gnd Wires #	Detune Towers #	No Action	Insulate Gnd Wires	Detune Towers	Wood Poles	Change Route	No Plan Yet	Insulate Gnd Wires	Detune Towers	Wood Poles	Change Route
New Brunswick	1												
Quebec	1			3				*	1				
Ontario		2	2	2			1		1	2		1	
Manitoba	1												
Saskatchewan				1									
Alberta								1	1				
B.C.	1						1						

* = Hydro Quebec retains a consultant. He has from time to time suggested rerouting of lines to avoid possible problems.

\# = In cases where the power line was there first, action on power utility lines was taken at the expense of the radio station.

The above information is based on three sources:

1. Questionnaire sent to AM radio stations by the Canadian Association of Broadcasters.
2. Phone conversations with six Canadian utilities and with the CBC.
3. Information obtained at a meeting of the D of C Working Group on Reradiation Problems in AM Broadcasting. (CEA is represented on this Working Group.)

ON CALCULATING THE IMPEDANCE ON MONOPOLE
ANTENNAS BY THE TRANSMISSION LINE METHOD

If you ask an antenna engineer today what he thinks about the transmission line approaches to calculating antenna impedance, he will tell you that the Schelkunoff days of back-to-the-envelope approximations are over and antenna engineers now use computer results (employing moment methods) as a matter of course (Hansen, private communications, 1979).

Nevertheless, transmission line methods may be the only practical approach to numerically calculate re-radiation from a very long power-line, although theoretical computations carried out in support of the re-radiation project have employed moment-method techniques (c.f. Chugh[1] and Balmain[2]). The computer program developed by Jones[3] employed a transmission line approach.

We have recently reviewed the methods developed by Siegel and Labus (c.f. Jordan and Balmain[4]) and Schelkunoff[5], who considered the antenna as an opened-out transmission line, since if accurate results for base impedance (reactance and radiation resistance) for simple monopole radiators cannot be obtained, there is little purpose in trying to extend these methods to include a row of towers connected by sky wires. We were well aware, e.g., that antenna engineers have more or less abandoned the transmission line method of Siegel and Labus, since it leads to resistance values that are consistently too high (c.f. Williams[6]); yet their transmission line method seems to be fundamentally right. In what follows we shall show that in fact the transmission line representation does give results that are as accurate as other analytical approximations.

Characteristic Impedance

There are about as many expressions for the average characteristic impedance of a monopole antenna as there are authors who have considered this approach. Schelkunoff[5] has given an expression, Siegel and Labus[4], Laport[7] and Howe[8] have given expressions. The only one that is consistent with measurement is that of Howe, which is:

$$Z_o = 60 \left(\log_e \frac{h}{a} - 1 \right) \tag{1}$$

where h = height of radiator
a = radius of the radiator

If the radiator is a square tower of side length b

$$a = 0.59 \, b \tag{2}$$

Data to support the above is given in Fig. 1, which compares the computed base reactance for a monopole antenna (the closed circles) with measured values (the continuous lines). The base reactance was calculated from

equations (3) and (4), (see below). For this monopole h/a = 203, and k was taken to be 1.05 (5% lengthening).

Base Reactance (H <0.2λ)

The base reactance for an electrically short antenna (H <0.2λ) is given by:

$$X_b = -j \, Zo \, Cot \, G \qquad (3)$$

where G = electrical height of the monopole.

The electrical height of monopole antenna (in degrees) is always greater than the physical height (in degrees) because of "end-effects", and because, when the monopole is thick, the velocity of propagation down it is less than the velocity of light. The relationship between G and H is given by:

$$G = kH \text{ degrees} \qquad (4)$$

where the factor k depends on the electrical diameter of the antenna (in degrees) and the electrical length of the antenna. This dependance experimentally determined is given in Fig. 2. In this figure the continuous lines have taken from model measurements made by Brown and Woodward[9]. The data points marked 1 are for the principle resonance, and the second and third resonances for a 400 foot broadcast antenna, that had a square cross-section 6½ feet on a side; given by Morrison and Smith[10]. Data point 2 is for the principle resonance for a model antenna, data for which are given in Fig. 1. Data points 3 were measured by Feldman (given in Schelkunoff[5]), and are for the second resonance.

Radiation Resistance (H <0.2λ)

The radiation resistance (referred to the base of the monopole) can be accurately calculated from the expressions:

$$Rr = 0.01215A^2 \text{ ohms} \qquad (5)$$

where A = degree-ampere current area on the antenna

For a monopole antenna (H <0.2λ)

$$A = \frac{180}{\pi} \left\{ \frac{1 - Cos \, G}{Sin \, G} \right\} \text{ degree-amperes} \qquad (6)$$

The expression is normalized to unity current at the base of the antenna, and the current distribution is assumed to be sinusoidal.

Base Impedance (H >0.2λ)

When the height antenna is greater than about 0.2λ, more accurate transmission line expressions must be employed to calculate the base impedance, since the above expression (equation 3) assumed a loss-less line. In the transmission line representation by Siegel and Labus (c.f. Jordan and

Balmain[4]) the radiated power is replaced by an equivalent amount of power dissipated as ohmic loss along the line. The following expressions are basically those derived by these authors, except that we have replaced the physical height H (in degrees) in their expressions by the electrical height G (degrees). This results in expressions which agree with experiments as well as other analytical approximations.

$$Rr = \frac{Zo}{2} \; \frac{Sinh\left(\dfrac{2\,Rr\,(loop)}{Zo}\right)}{Cosh^2\left(\dfrac{Rr\,(loop)}{Zo}\right) - Cos^2 G} \tag{7}$$

$$X_b = -j\,\frac{Zo}{2} \; \frac{Sin\,2\,G}{Cosh^2\left(\dfrac{Rr\,(loop)}{2}\right) - Cos^2 G} \tag{8}$$

where Rr (loop) is the radiation resistance referred to the current loop. Curves that give the loop radiation resistance are given in various publications (c.f. Jasik[11]), or, with fair approximation it can be calculated from the expression:

$$Rr\,(loop) = 15\left[-\frac{\pi}{2}\,Sin\,2G + \left(log_e\,\frac{G}{180} + 1.722\right)Cos\,2G \right.$$
$$\left. + 4.83 + 2\,log_e\,\frac{G}{180}\right] \text{ ohms} \tag{9}$$

We show in Figs. 3 and 4 a comparison between calculated values for Rr and X_b (labelled Belrose) employing Equations (7), (8), and (9), where the electrical height of the monopole is determined from Equation 4 and Fig. 2, with measured values by Morrison and Smith[10]. We show also the impedances predicted by Schelkunoff[5]. Agreement between calculated and measured impedances employing the expressions given above that are closer to experiment can be achieved if measured electrical heights are used in the expressions, instead of those given by Brown and Woodward[9], see Fig. 2. The usefulness of these expressions depends on the accuracy with which the electrical height G can be determined from the physical height H and electrical diameter D of the monopole.

Finally, we consider the measurements by Morrison and Smith to be most suitable for comparison with theory. The radiator was of uniform cross-section, and the base capacitance was said to be 30 μμfd. In general the base capacitance for broadcast antennas typically employed is much higher, perhaps ~60 μμfd. A towerlighting transformer and spark gap will add another 75 μμfd in parallel with the base insulator. If tower-lighting power is fed through an isolating inductor, an inductive reactance may appear across the base insulator, which neutralizes a portion of the base-insulator capacitive reactance (c.f. Laport[12]). The net result is that the resonant frequency for broadcast antennas employed in Canada is lower in frequency than measured by Morrison and Smith, and lower than calculated above. The curves in Fig. 2 are for zero base capacitance. Curves based on

On data measured at some sixty (perhaps more) broadcast stations are given by Mather[13].

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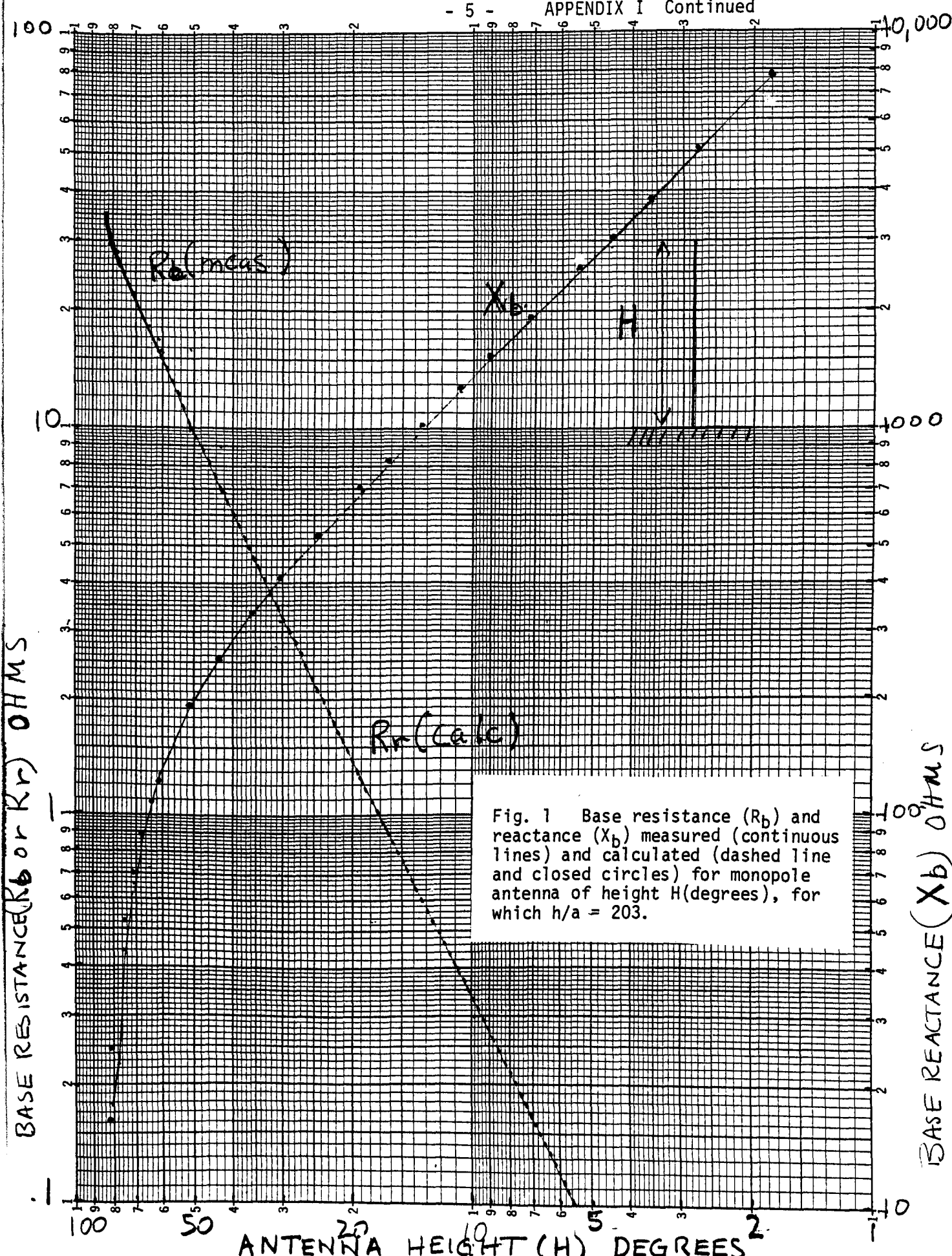Ottawa, Ontario

6 February 1979

Fig. 1   Base resistance (R_b) and reactance (X_b) measured (continuous lines) and calculated (dashed line and closed circles) for monopole antenna of height H(degrees), for which h/a = 203.
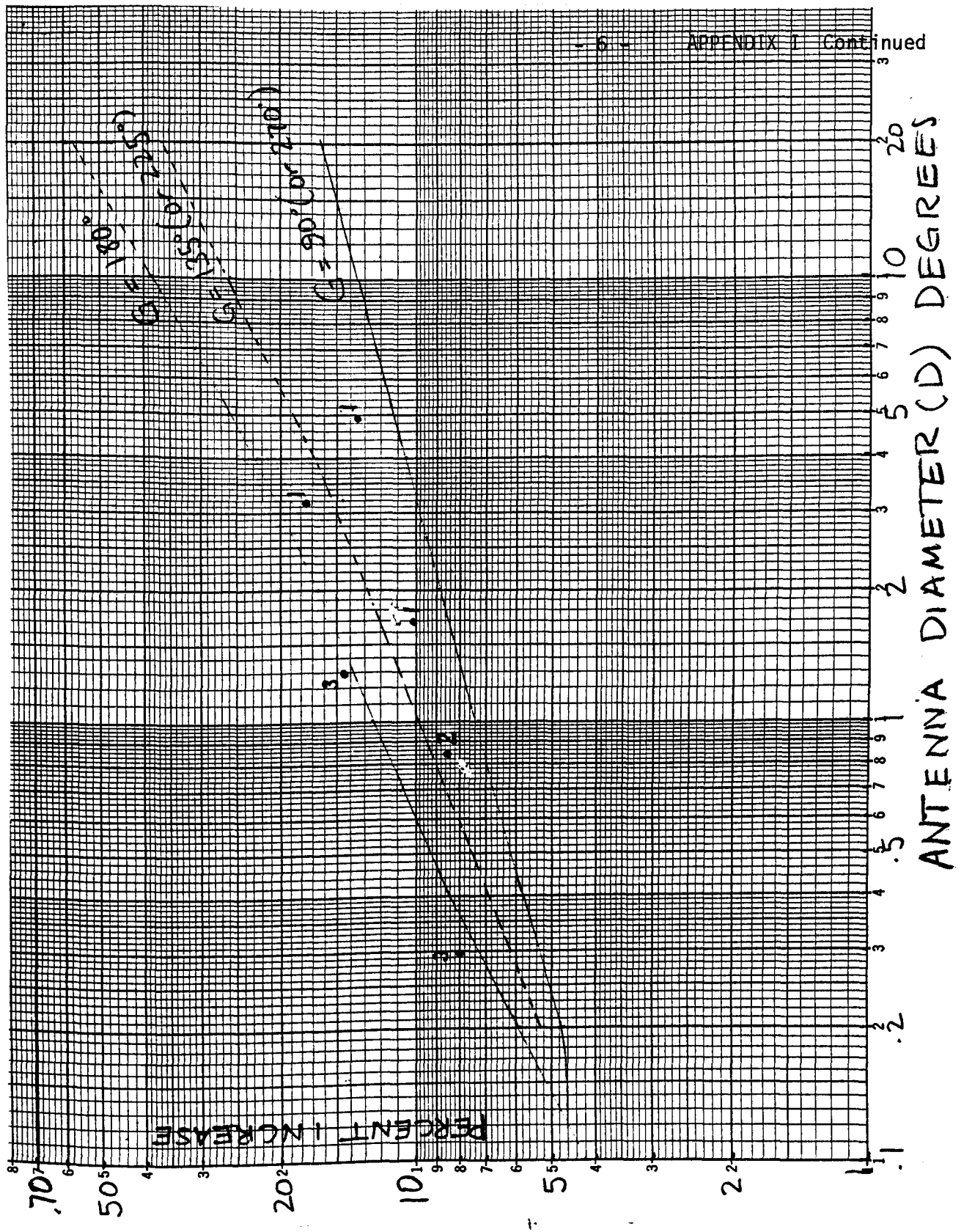
Fig. 2   Dependance of electrical
height (G) measured as a percent
over the physical height (H) on
monopole diameter (D) and electri-
cal height
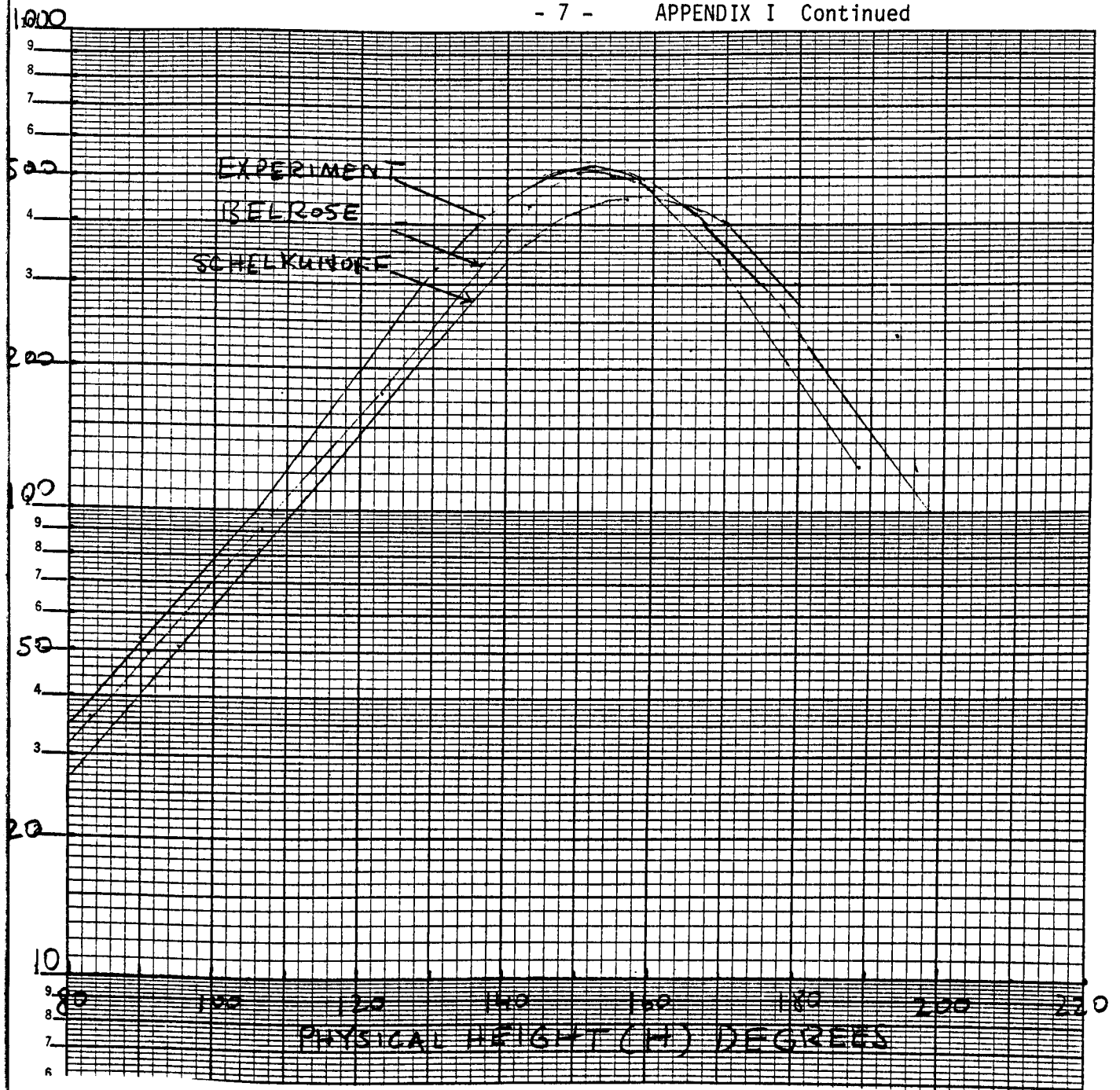
Fig. 3   Calculated (Rr) and measured
base resistance (R_b) for a broadcast
antenna of height 400 feet, having a
square cross-section (6½ feet on a
side).
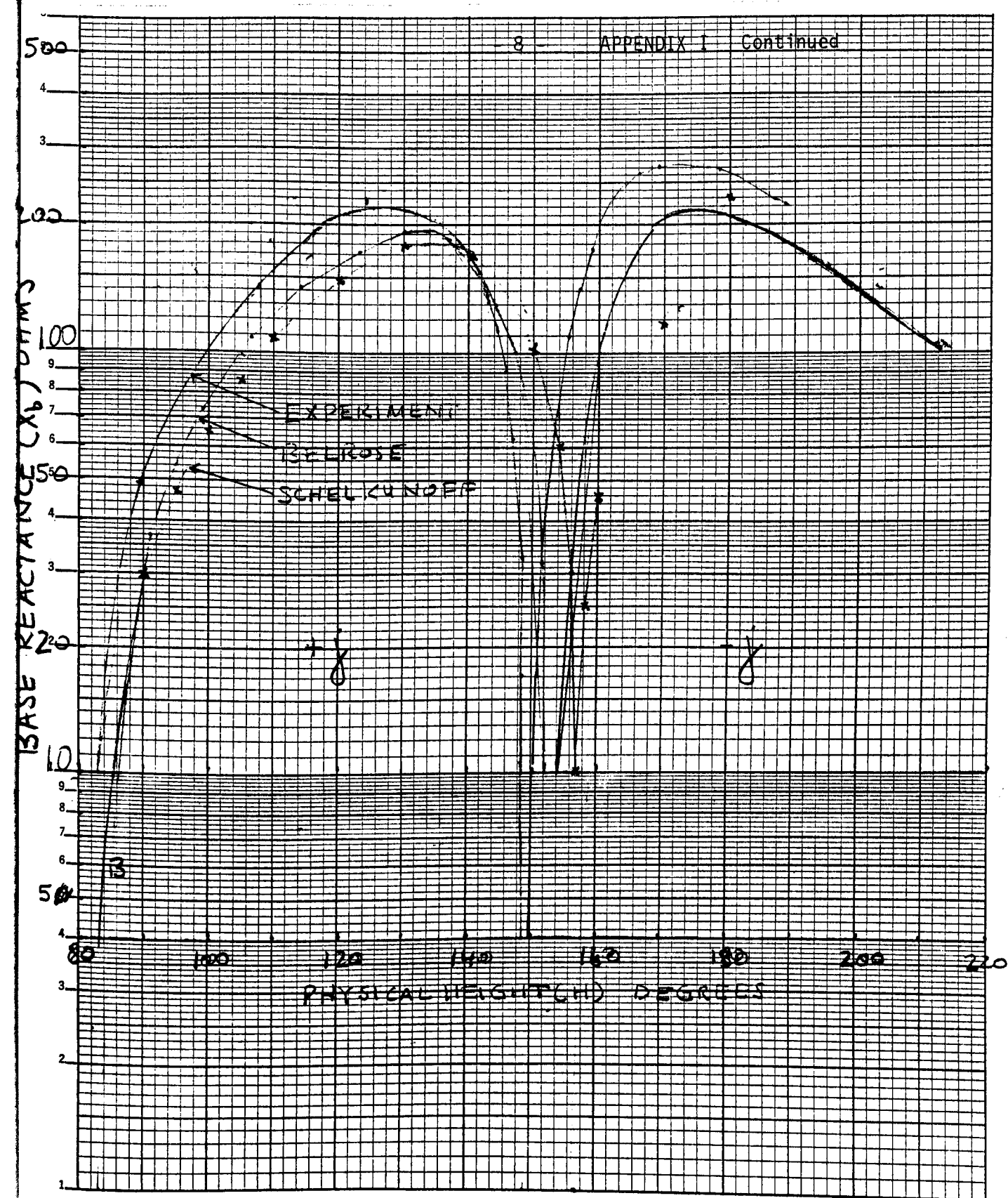
Fig. 4 Calculated and measured base reactance
(X_b) for a broadcast antenna of height 400 feet,
having a square cross-section (6½ feet on a side)

REFERENCES

1. Chugh, R., *Analytical Model for Re-Radiation from Thin Towers, Interim Reports Nos. 2 and 3*, 2 February 1978 and 18 May, 1978.

2. Balmain, K. G., *this report, Appendix 3*.

3. Jones, D. E., *Modelling a Powerline as a Parasitic Array, Hydro-Electric Power Commission of Ontario*, Report No. 74-17-H, dated 17 January 1974 (Restricted Information).

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5. Schelkunoff, S. A., *Theory of Antennas of Arbitrary Size and Shape*, Proc. I.R.E., 29, 493-521, 1941.

6. Williams, H. P., *Antenna Theory and Design*, pp. 48-55, Sir Isaac Pitman and Sons, London, 1950.

7. Laport, E. A., *Radio Antenna Engineering*, p. 31, McGraw Hill Book Co., 1952.

8. Howe, G.W.O., *On the Capacity of Radio-Telegraphic Antennae*, Electrician, 73, p. 829, 1914.

9. Brown, H., and Woodward, O. M., *Experimentally Determined Impedance Characteristics of Cylindrical Antennas*, Proc. I.R.E., 33, pp. 257-262, 1945.

10. Morrison, J. F., and Smith, P. H., *The Shunt-Excited Antenna*, Proc. I.R.E., 25, pp. 673-696, 1937.

11. Jasik, H. (Editor), *Antenna Engineering Handbook*, p. 20-5, McGraw Hill Book Co., 1961.

12. Laport, above cite, p. 114.

13. Mather, G., *private communications*, January 1952.

INTERIM REPORT #4 ON NRC WORK

Introduction

This report deals with tests carried out in October 1978 on a scale model of the CBL/CJBC transmitter site at Hornby, Ontario.

Preliminary tests outlined in Interim Report #3 (19-9-78) were carried out using a very simplified layout of transmission line towers to model the Hornby situation. At that time, only one row of equally spaced towers was used and all towers were placed in a straight line. For the patterns shown in the present report, a more realistic model employing twenty-seven towers was set up using location data supplied by Ontario Hydro.

Scale Model of CBL/CJBC Site

The geometry of the site is shown in Fig. 1. A total of 27 towers were placed on the turntable in their proper scale position. See the enclosed photograph. As before, a scale factor of 600 was used. The test frequencies were 444 MHz (CBL) and 516 MHz (CJBC).

Several patterns were obtained with and without skywires and phase wires. Various combinations of skywire grounding and isolation were investigated. As can be seen in the photograph of the model, both sides of the tower arms were fitted with wires as in real life, that is, each tower carried two skywires and six phase wires.

Some typical patterns are shown in Figs. 2 to 11. The location of the transmission line can be obtained by directly superimposing Fig. 1 onto the patterns with the broadcast antenna placed at the center.

Examination of the patterns obtained indicates the following:

1. The towers alone produce an appreciable pattern distortion.
    See Figs. 2 and 7.

2. Addition of the skywires has a more pronounced effect at 516 MHz (CJBC) than at 444 MHz (CBL). Compare Figs. 3 and 8. This is probably caused by the fact that the tower spacing is such that a resonant loop is formed at 516 MHz, thereby increasing the tower currents.

3. Addition of the phase wires has almost a negligible effect. Compare Fig. 3 with Fig. 4. Also Fig. 8 with Fig. 9.

4. Lifting, breaking and/or isolating portions of the skywires appears to produce no significant improvement. This can be seen not only on Figs. 4, 5 and 6 but also in many other patterns obtained using other configurations not shown in this report.

Conclusion

The use of scale model techniques has allowed rapid assessment of various skywire configurations in an attempt to find one which will produce minimum pattern distortion.

With the evidence at hand, it appears that no such optimum configuration exists. In any case, if the effect of the skywires can be completely eliminated by some fortuitous geometry, the net effect would be that obtained with the towers alone, such as Fig. 2., which is still a considerable departure from the original onmidirectional pattern.

The conclusion then is that something must be done with the towers themselves to reduce the amplitude of the R.F. current flowing on them. One possible solution, impractical as it may be from other considerations, would be to break the tower into several sections and insulate each portion from the adjacent ones.

J. G. Dunn
W. Lavrench

Electromagnetic Engineering Section
Division of Electrical Engineering
National Research Council of Canada

16 January 1979

TOWER #21 ↗   ← TOWER # 1

1000 FT.
|←———→|

← C BL/CJBC
   ANTENNA

TOWER #33

N

TOWER #14
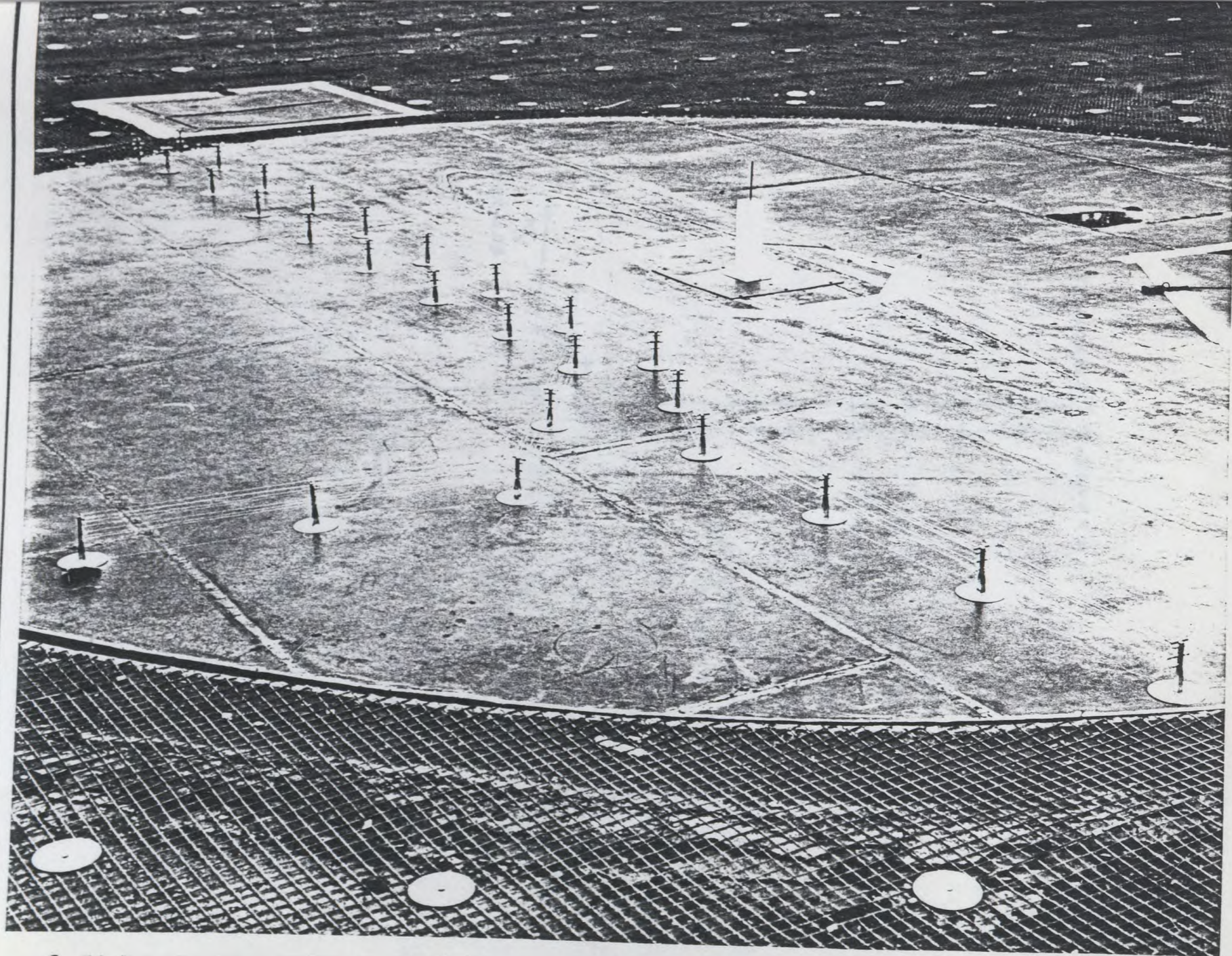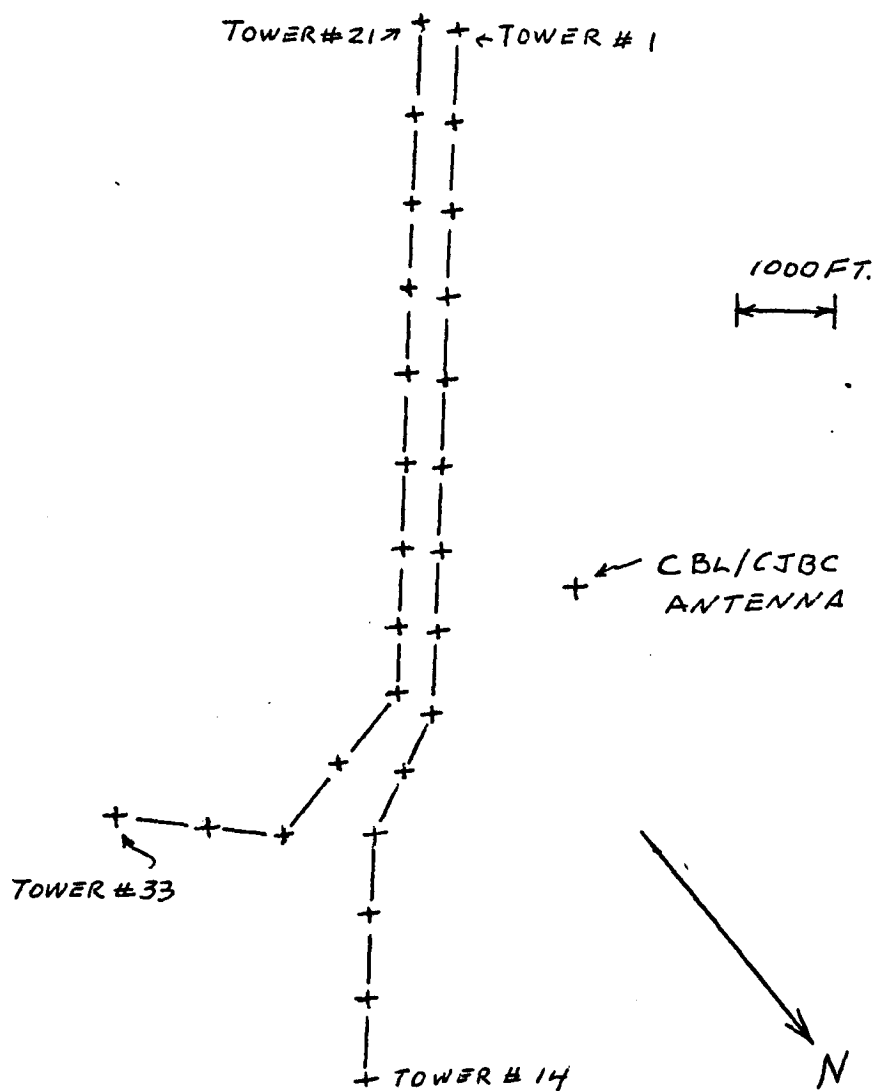
FIG. 1
CBL/CJBC SITE
HORNBY
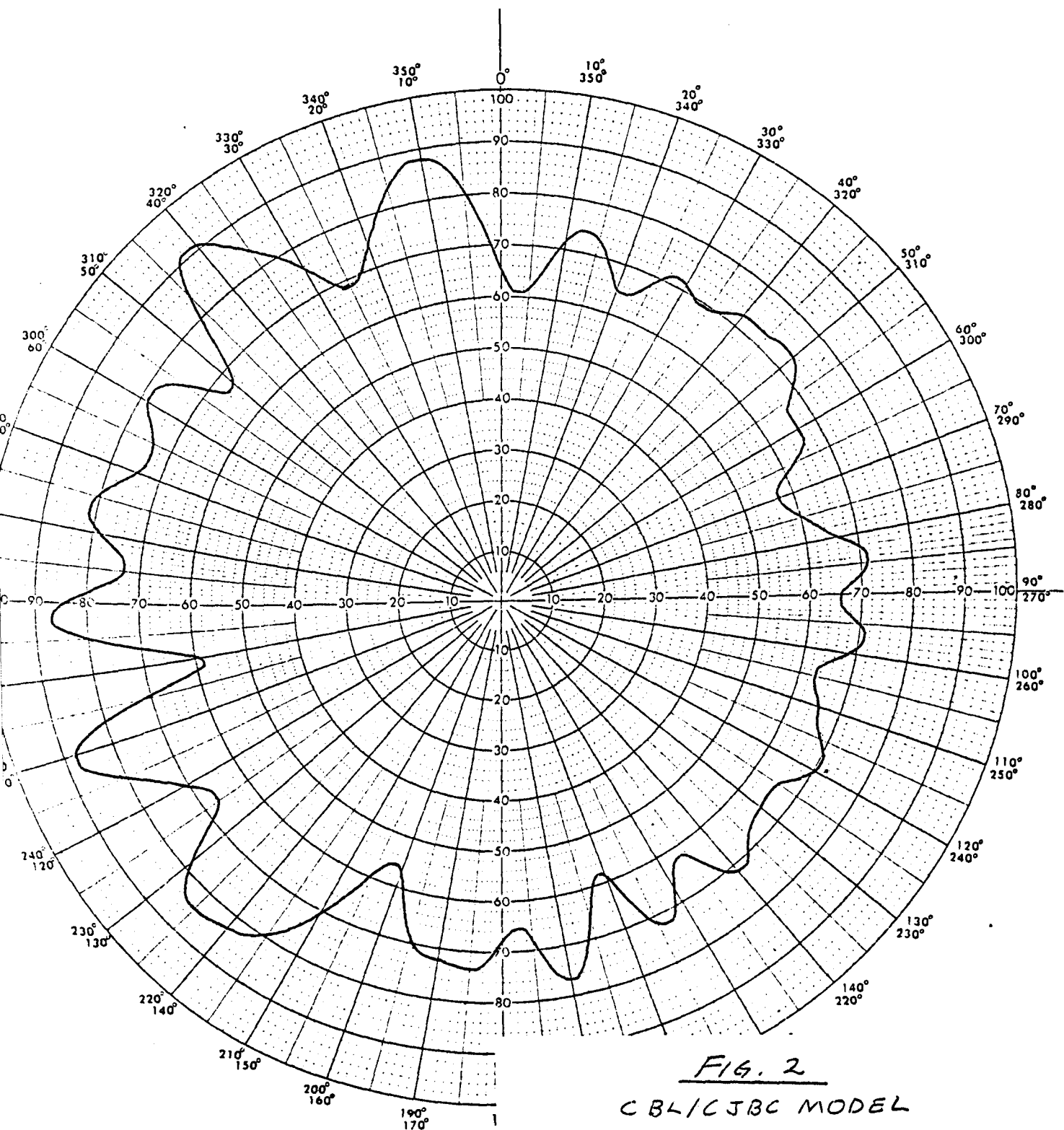
FIG. 2
CBL/CJBC MODEL
TOWERS ONLY
516 MHZ (CJBC)
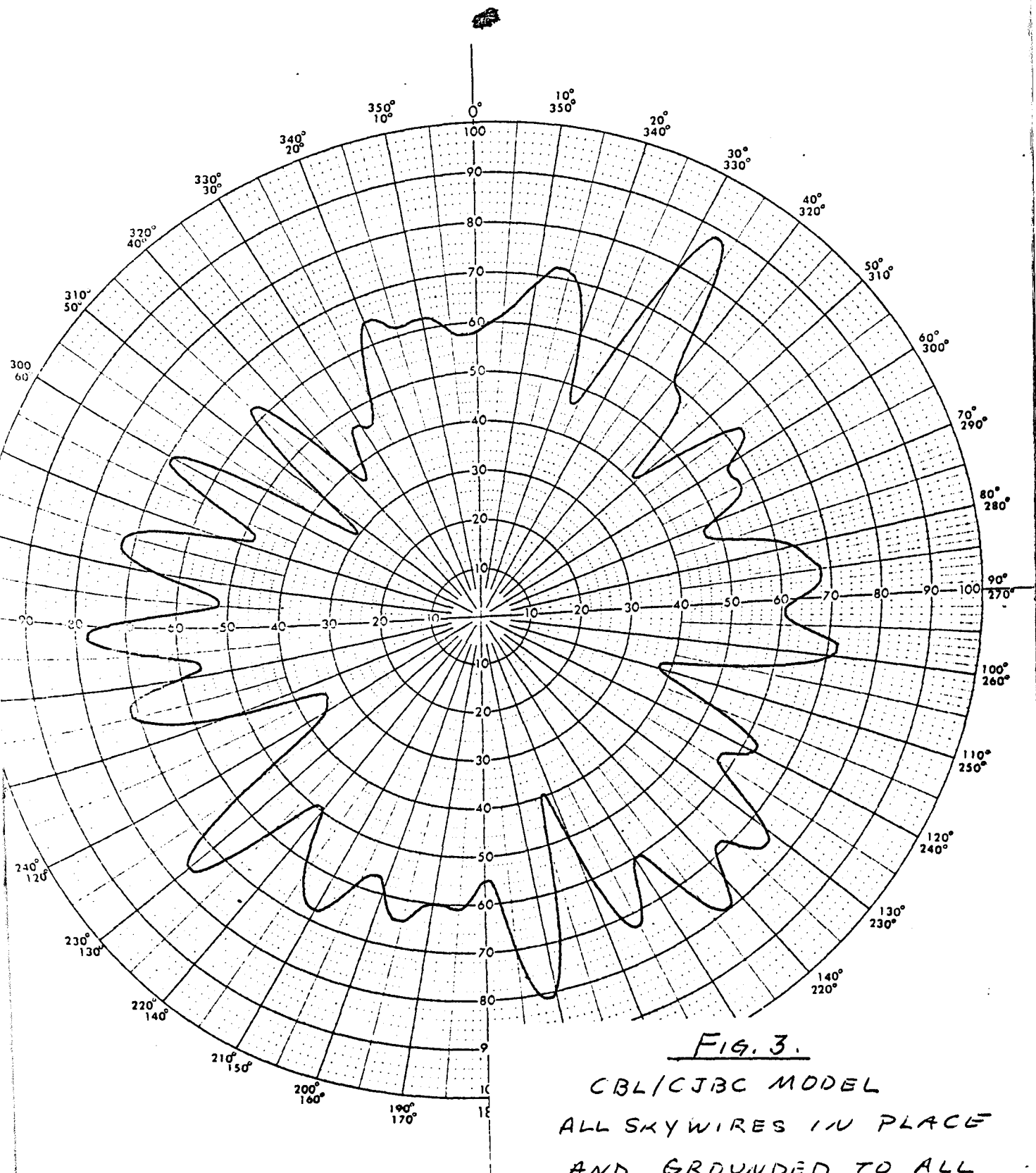
19 OCT 1978

FIG. 3.

CBL/CJBC MODEL
ALL SKYWIRES IN PLACE
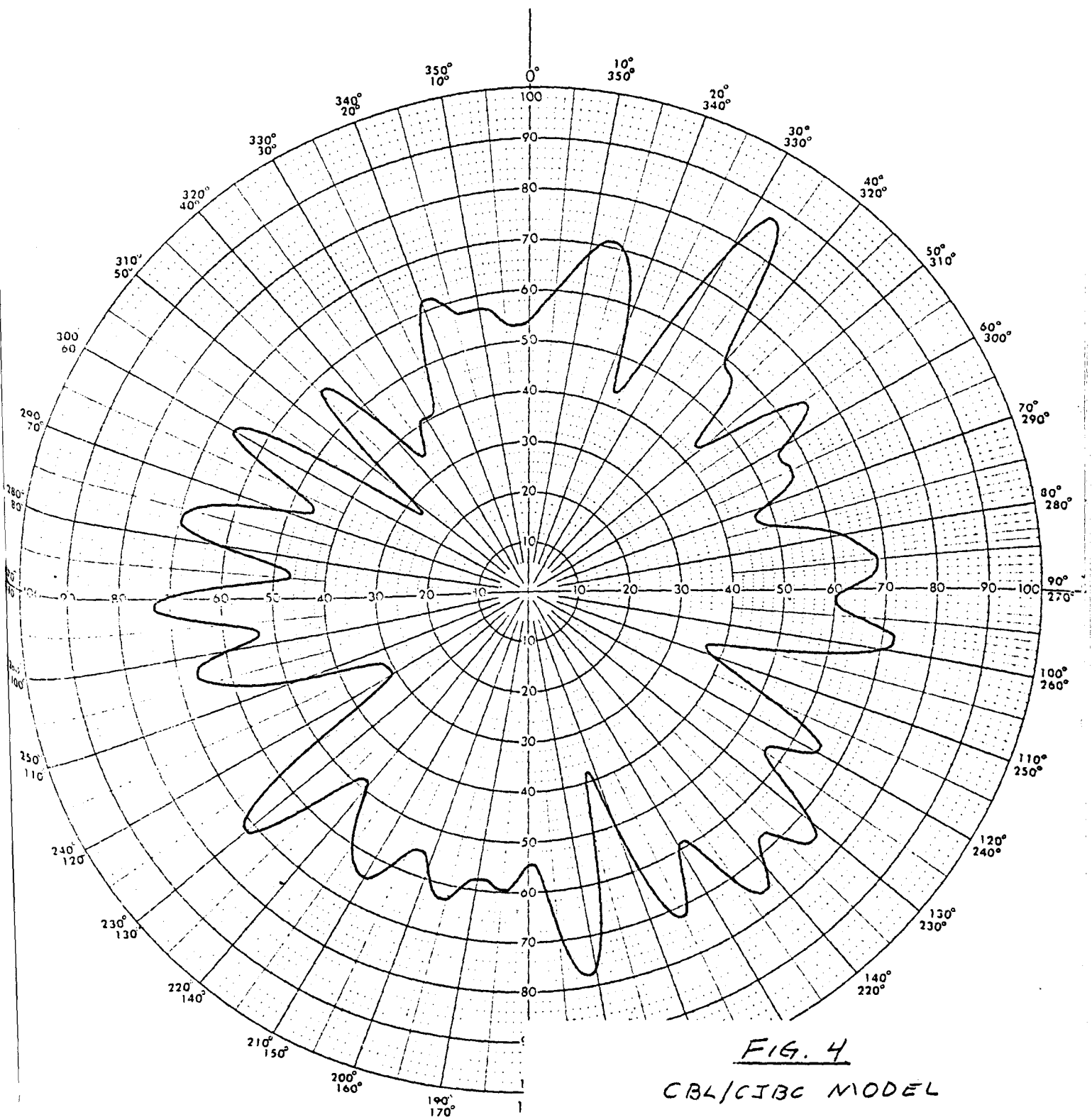AND GROUNDED TO ALL
TOWERS
516 MHz (CJBC)

19 OCT 1978

FIG. 4
CBL/CJBC MODEL
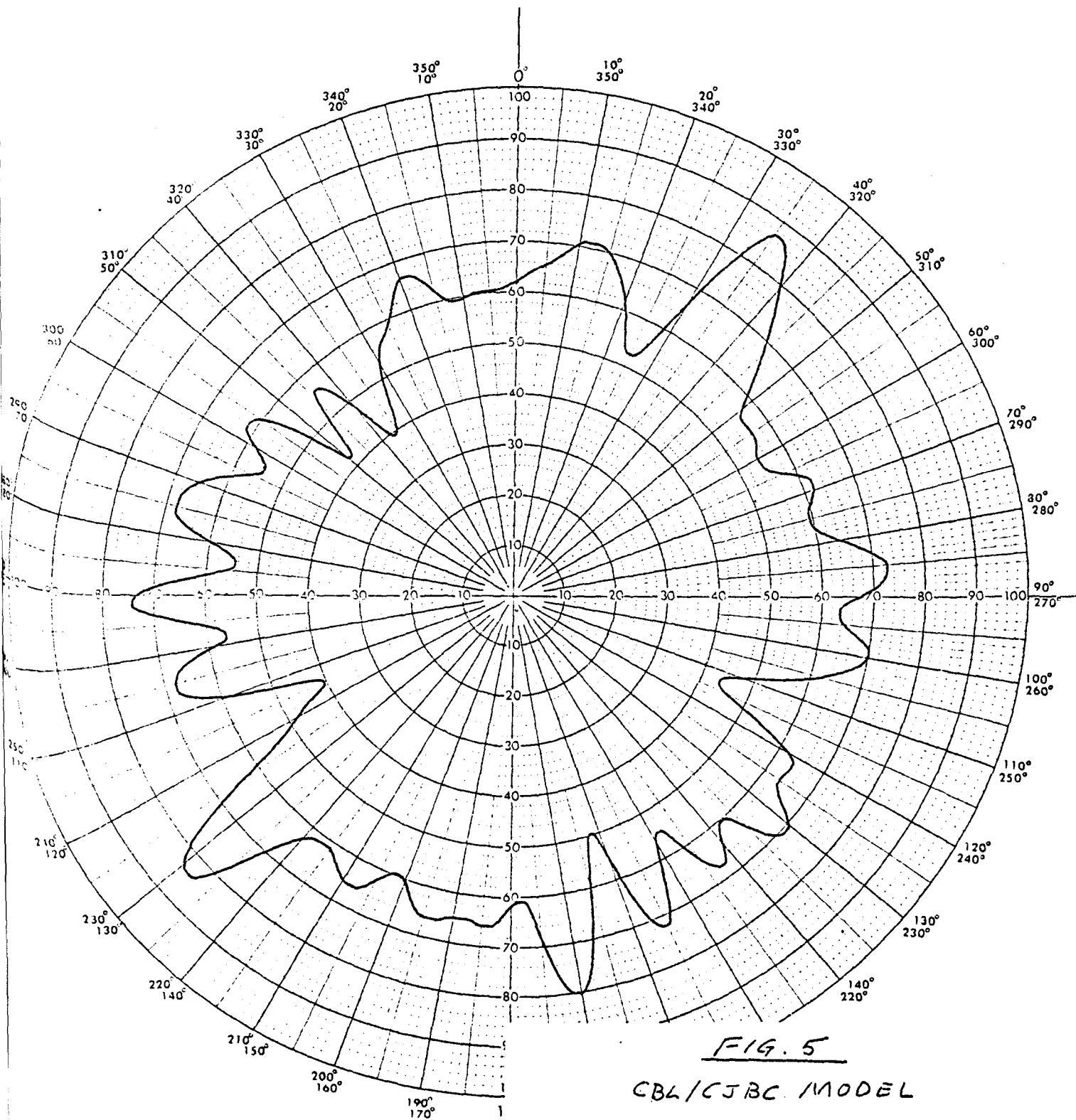ALL SKY WIRES AND PHASE
WIRES IN PLACE
516 MHZ (CJBC)

FIG. 5

CBL/CJBC MODEL

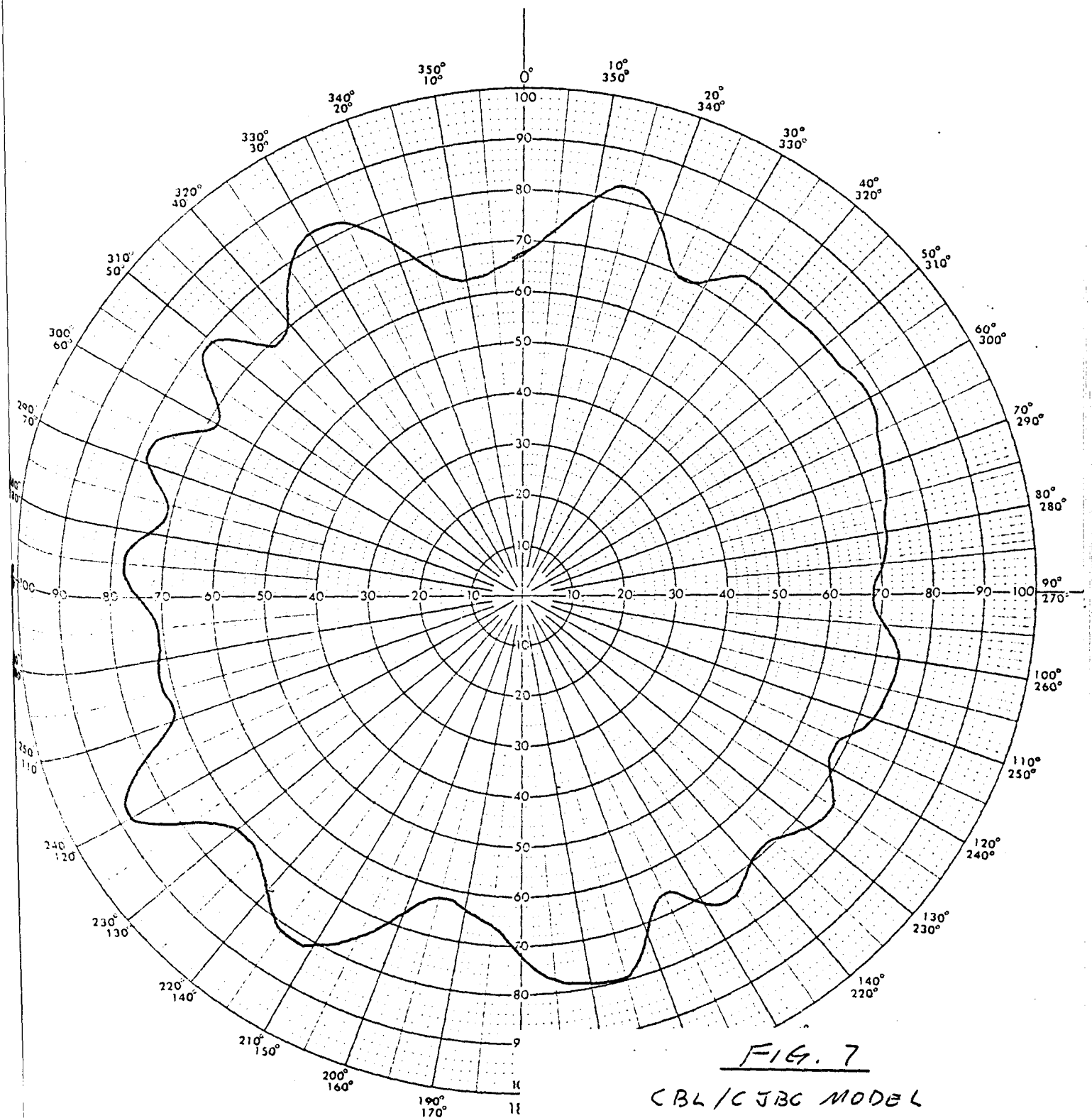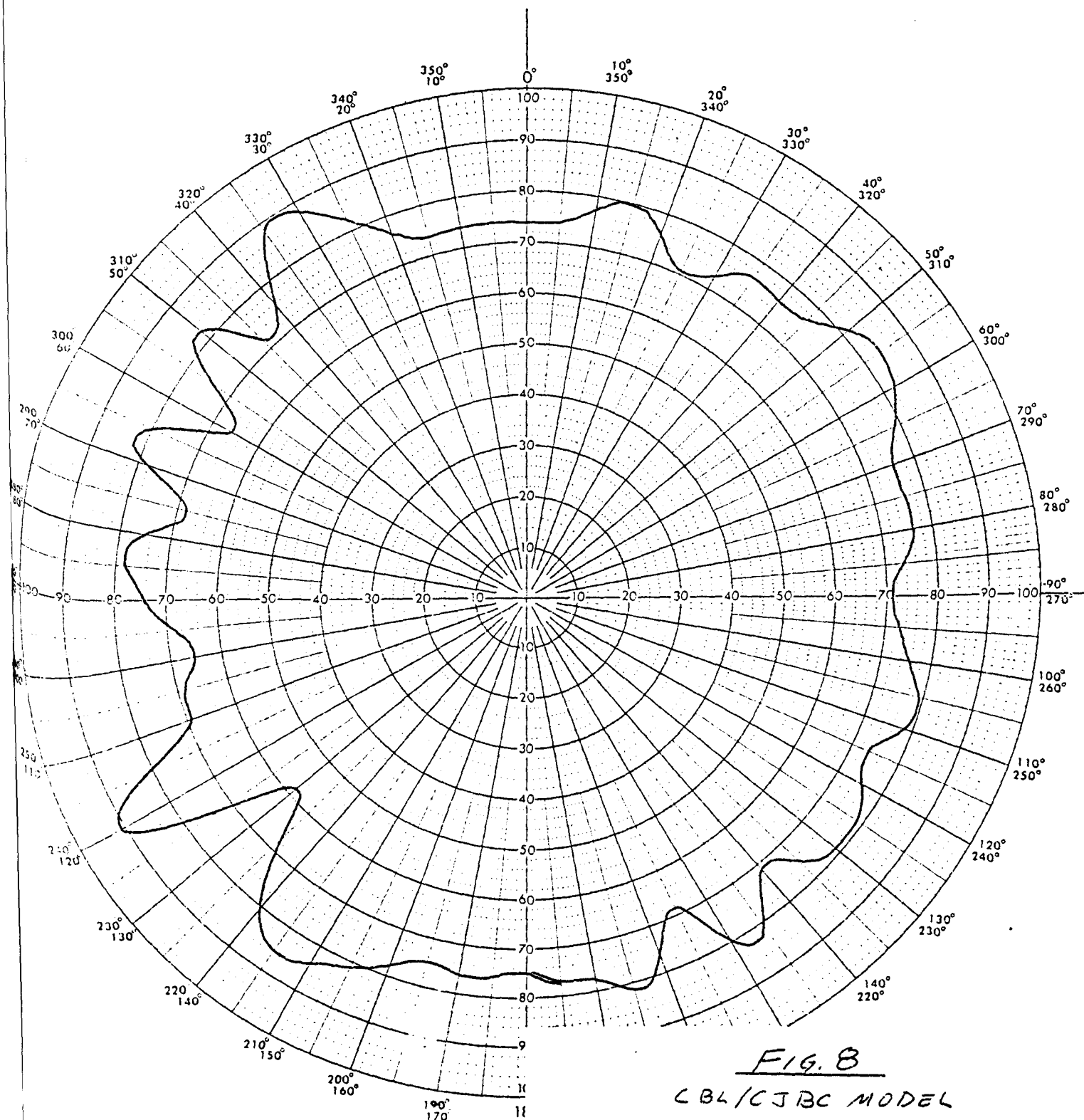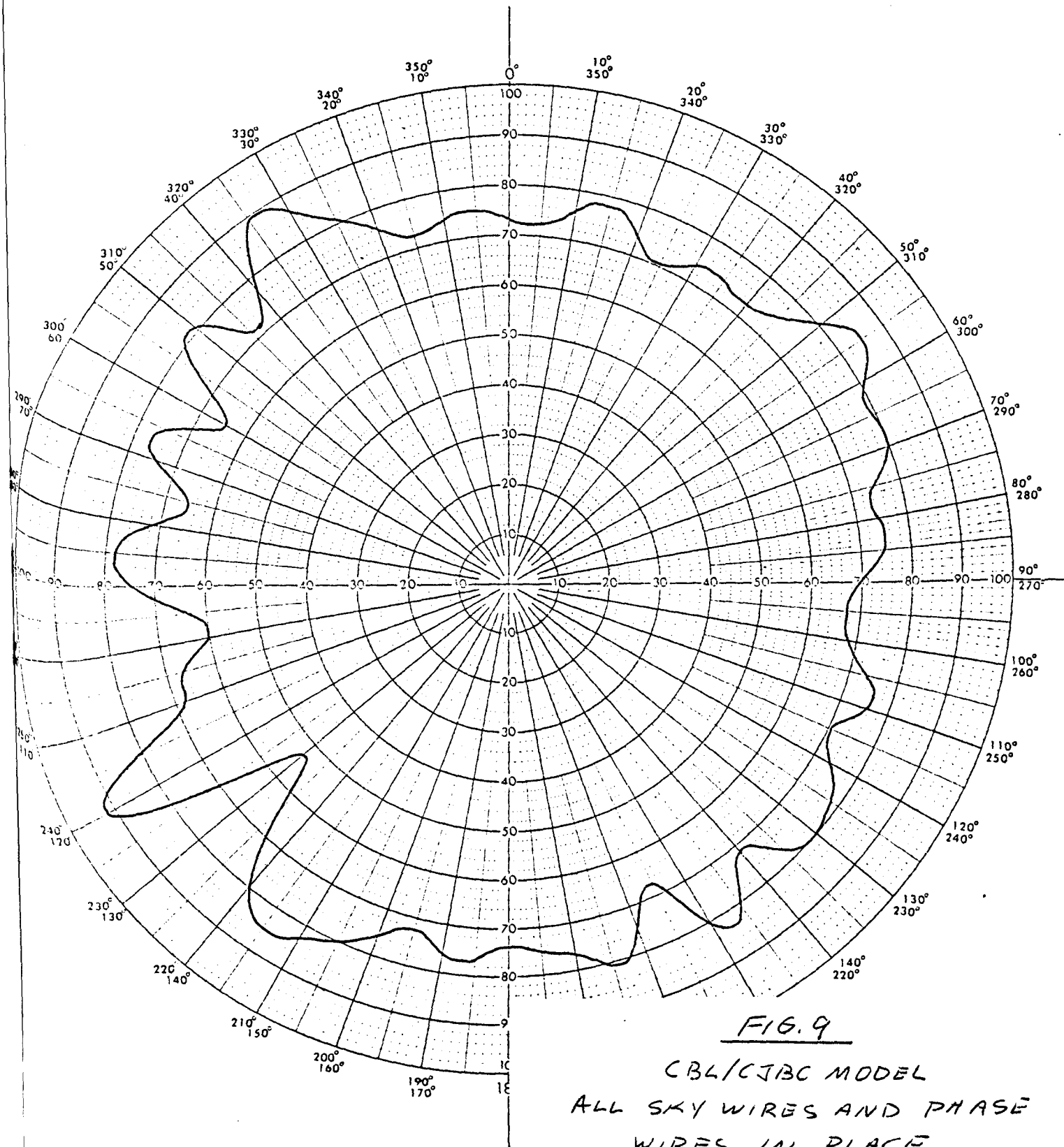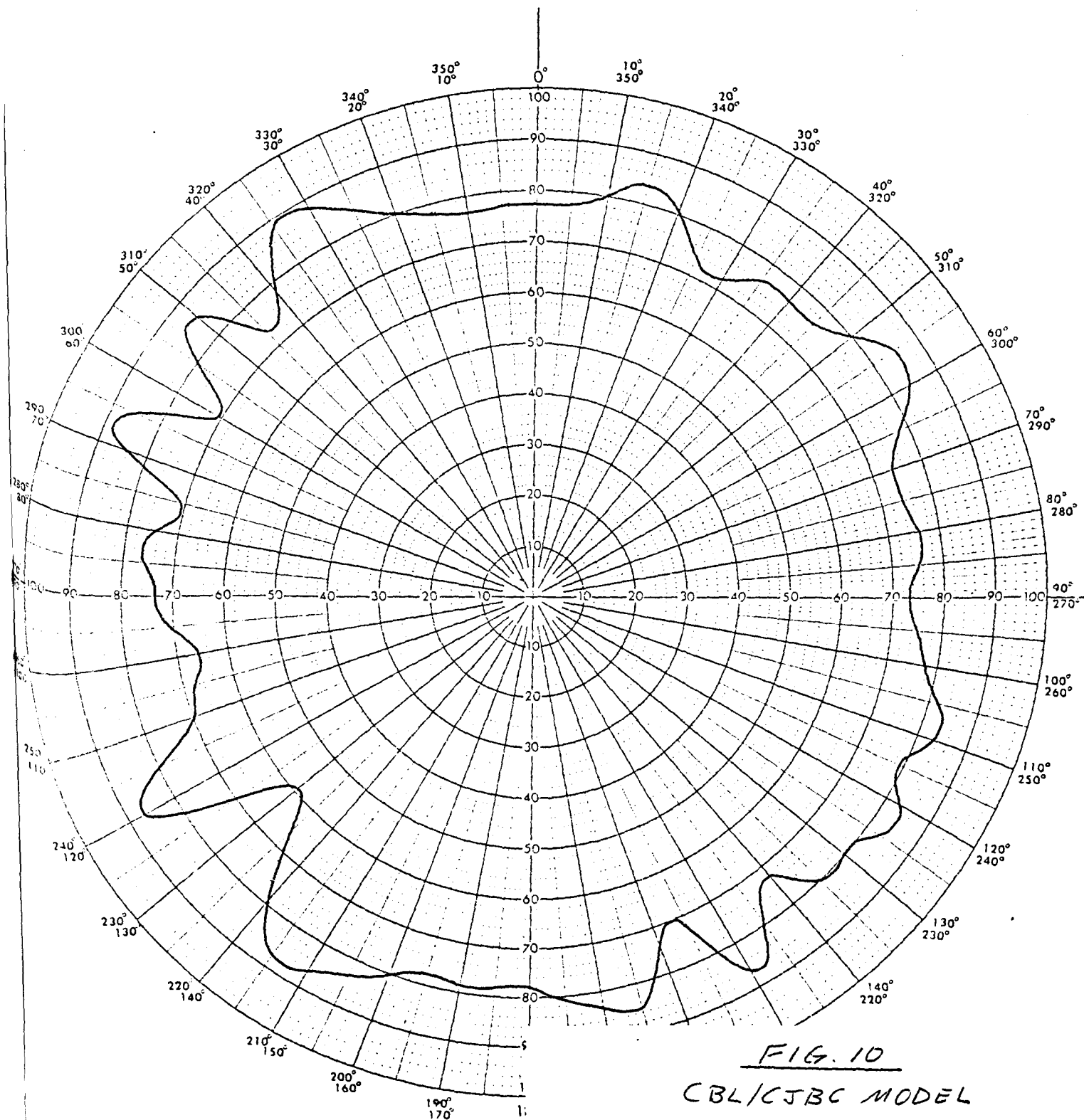AS IN FIG. 4 BUT SKYWIRES
GROUNDED ONLY AT TOWERS
#1, 5, 9, 13, 21, 25, 29 AND 33
516 MHz (CJBC)
19 OCT 1978

GC-127L (GC 1224-R)
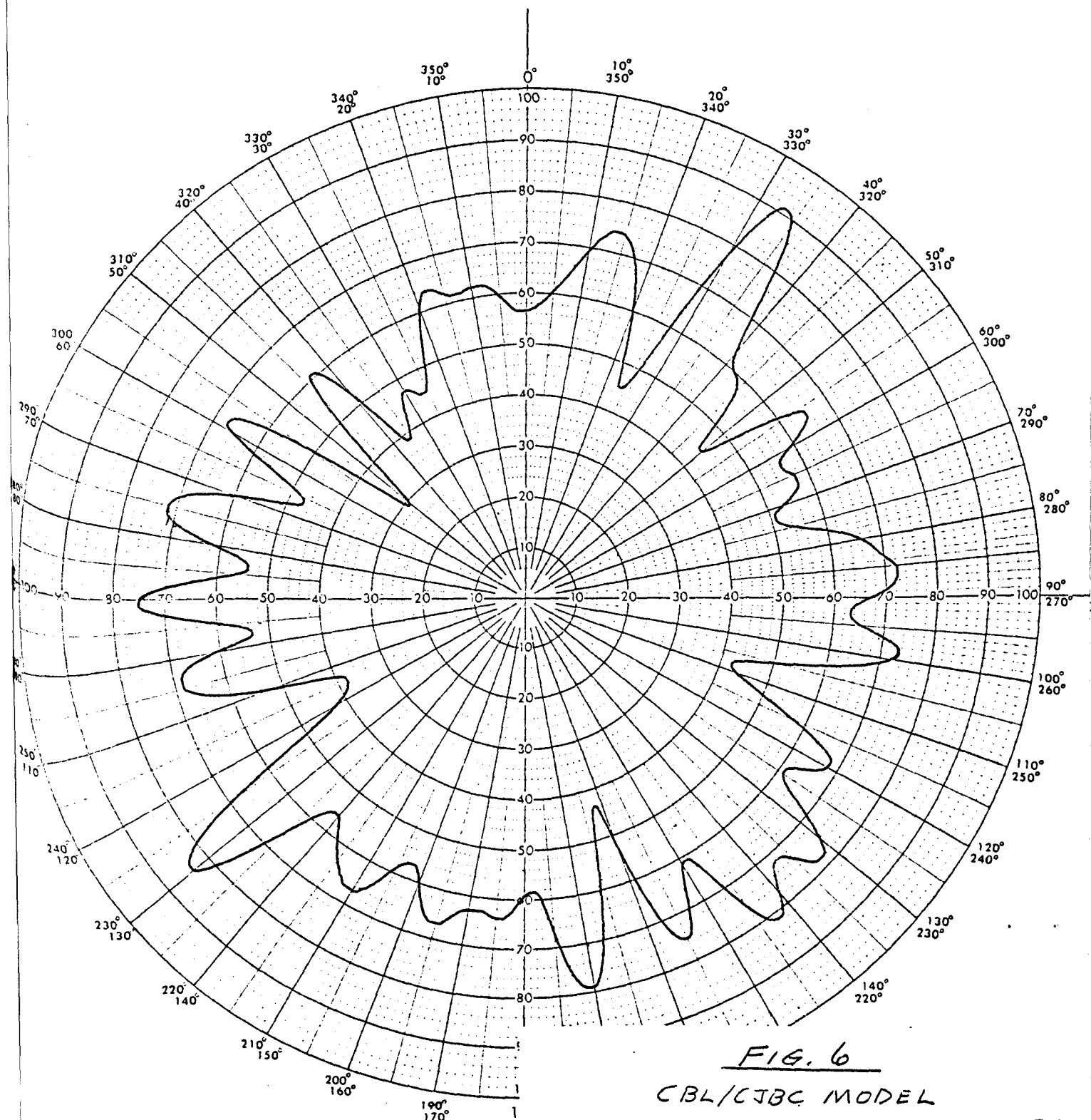
FIG. 6

CBL/CJBC MODEL
AS IN FIG.4 BUT SKY WIRES
BROKEN AND INSULATED AT TOWERS
9, 11, 29 AND 31
516 MHz (CJBC)

19 OCT 1978

GC-127L (GC 1224-R)
CONTROLS CANADA LTD

FIG. 7

CBL/CJBC MODEL
TOWERS ONLY
444 MHz (CBL)

19 OCT 1978

GC-127L (GC 1224-R)
ANTHONY CANADA LTD

FIG. 8

CBL/CJBC MODEL

ALL SKYWIRES IN PLACE

AND GROUNDED TO ALL TOWERS

444 MHZ (CBL)

19 OCT 1978

FIG. 9

CBL/CJBC MODEL
ALL SKY WIRES AND PHASE
WIRES IN PLACE
444 MHz (CBL)

GC-127L (GC 1224-R)

19 OCT 1978

FIG. 10
CBL/CJBC MODEL
AS IN FIG. 9 BUT SKYWIRES
GROUNDED ONLY AT TOWERS
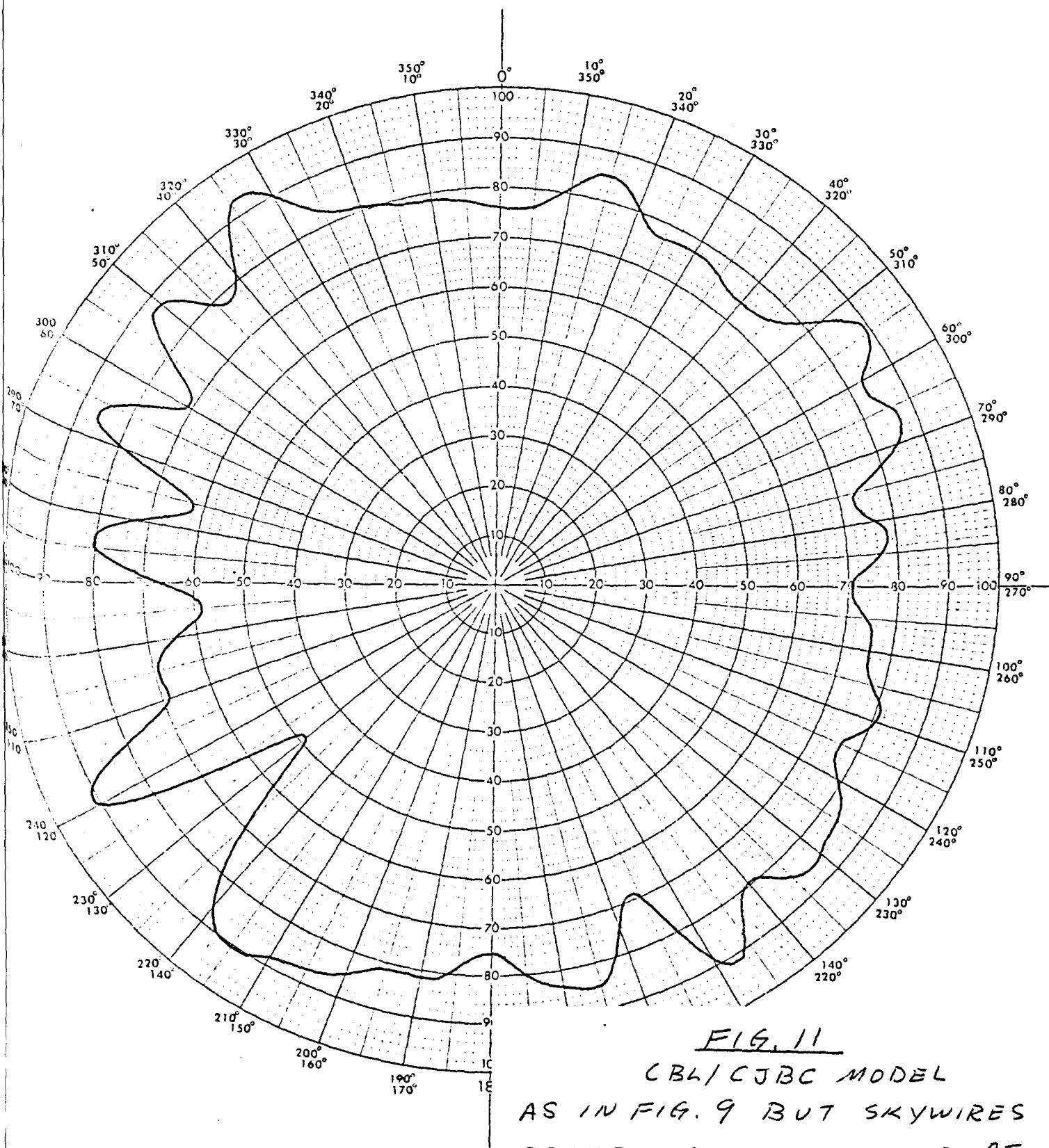#1, 5, 9, 13, 21, 25, 29 AND 33
444 MHz (CBL)

19 OCT 1972

FIG. 11
CBL/CJBC MODEL
AS IN FIG. 9 BUT SKYWIRES
BROKEN AND INSULATED AT
TOWERS # 9, 11, 29 AND 31
444 MHZ (CBL)

19 OCT 1978

GC-127L (GC 1224-R)

INTERIM REPORT ON UNIVERSITY OF TORONTO WORK

1. STATUS

The period November 1978 to January 1979 has been devoted to numerical computation using the moment-method computer program. Almost all of this work was on re-radiation from power lines, and some of it was carried out on a cooperative basis with Ontario Hydro.

2. COMPUTATIONS FOR THE HORNBY SITE

Mr. Mark Vainberg of Ontario Hydro, working under the direction of Mr. D.E. Jones, set up a mathematical model for the Hornby site and ran it using the University of Toronto moment-method computer program and computer facilities. The model included seven towers on each of the two power lines and used the actual tower locations which pass the CBC antenna at a distance of approximately one wavelength. The model subdivided all wires (including the CBC transmitting antenna) into a total of 82 segments, and represented each power line tower as a single vertical wire of the same diameter as the skywires. For some calculations an artificially large skywire diameter was used to take into account the actual presence of two skywires. Ground losses were not included but wire conductivity was included.

The results showed very much less pattern perturbation than measured for the case of towers without skywires. With skywires grounded to all towers, the pattern perturbations were roughly the same order of magnitude as those measured, but their directions were not the same. Isolation of four towers in each line produced a slight reduction in pattern perturbation. Overall, there seemed to be little correlation amongst any pair of the three sets of patterns available, i.e., those measured, those calculated by the University of Toronto program, and those calculated by Ontario Hydro program.

3. A LARGER POWER LINE MODEL

To test the feasibility of more complex power line computational models, a model with 106 segments was set up, involving 11 towers at a distance of three wavelengths from a single transmitting tower. Between towers, each skywire was subdivided into four segments, but each tower was represented as a single vertical wire. Scattered signal levels of -17 dB to -25 dB were noted, similar to non-resonant

cases studied experimentally last year [1]. No computational dif-
ficulties were experienced due to either the large number of
segments or the relatively large distance between the antenna and
the power line.

4. THE "A-FRAME" TOWER MODEL

In last year's Final Report [1], it was noted that computa-
tions on a five-tower power line predicted the lowest-frequency
resonance to occur at a frequency 10% lower than that actually meas-
ured. Furthermore the predicted radiation pattern "notch" was about
2 dB too shallow, and the small secondary resonance was too widely
separated in frequency from the primary resonance.

It would appear that a lower-impedance mathematical model for
the towers could correct all the above factors. The lower induc-
tance would raise the resonant frequency, the lower tower impedance
might cause more current to flow (producing more re-radiation),
and the lowered coupling between adjacent-cell resonators should
bring the primary and secondary resonances closer together. To
achieve the lower tower impedance it was decided to use the "A-frame"
model shown in Fig. 1, each leg of the frame having the same diameter
as the skywire.

The swept-frequency graph of signal transmission straight through
the power line is shown in Fig. 2 from which it is clear that the fre-
quency of the primary notch has been predicted almost exactly. In
fact the A-frame correction seems to have overshot the mark slightly,
with the resonance too strong and sharp, and very slightly too high in
frequency. However there remain some adjustments to make, so that
the probability is high that even better agreement with experiment
can be achieved. Corresponding radiation patterns are shown in Fig. 3.

For the remainder of the contract duration, emphasis will be
placed on refinement of the computational model along the lines indi-
cated above, in order to achieve good agreement with experiments.
Similar techniques will also be applied to high-rise buildings. In addi-
tion the original piecewise-sinusoidal-current computer program [2,3]
will be further modified to make it more suitable for the re-radiation
computations.

5.   PAPER PRESENTATION

A paper entitled "AM Broadcast Re-Radiation from Buildings and Power Lines " by K.G. Balmain and J.S. Belrose was presented at the IEE International Conference on Antennas and Propagation, London, England, 28-30 November 1978. The paper contained material from last year's contract; a copy of the paper is attached.

6.   REFERENCES

[1]   Balmain, K.G., "The Effects of Re-Radiation of AM Broadcast Signals", Final Report on DOC/DSS Contract Ser. No. OSU77-00288, March 1978.

[2]   Richmond, J.H., "Radiation and Scattering by Thin-Wire Structures in the Complex Frequency Domain", NASA Contractor Report CR-2396, 1974.

[3]   Richmond, J.H., "Computer Program for Thin-Wire Structures in a Homogeneous Conducting Medium, NASA Contractor Report CR-2399, 1974.

29 January 1979

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FIG. 1 The power line computational model employing the "A-frame" tower representation.
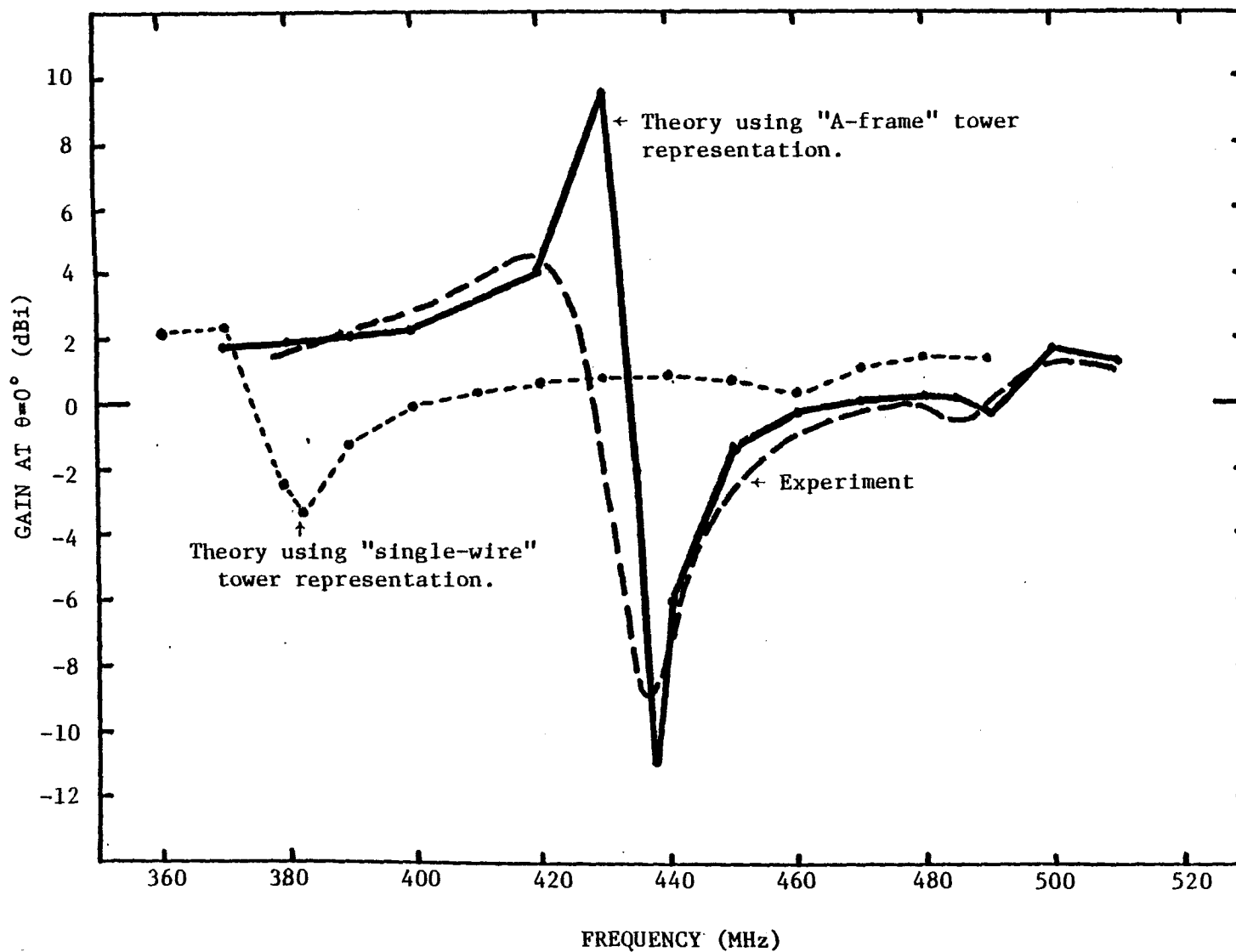
FIG. 2 The first resonance for the five-tower power line for a distance d'=0.8m
between the line and the antenna. Note the correction for observation-
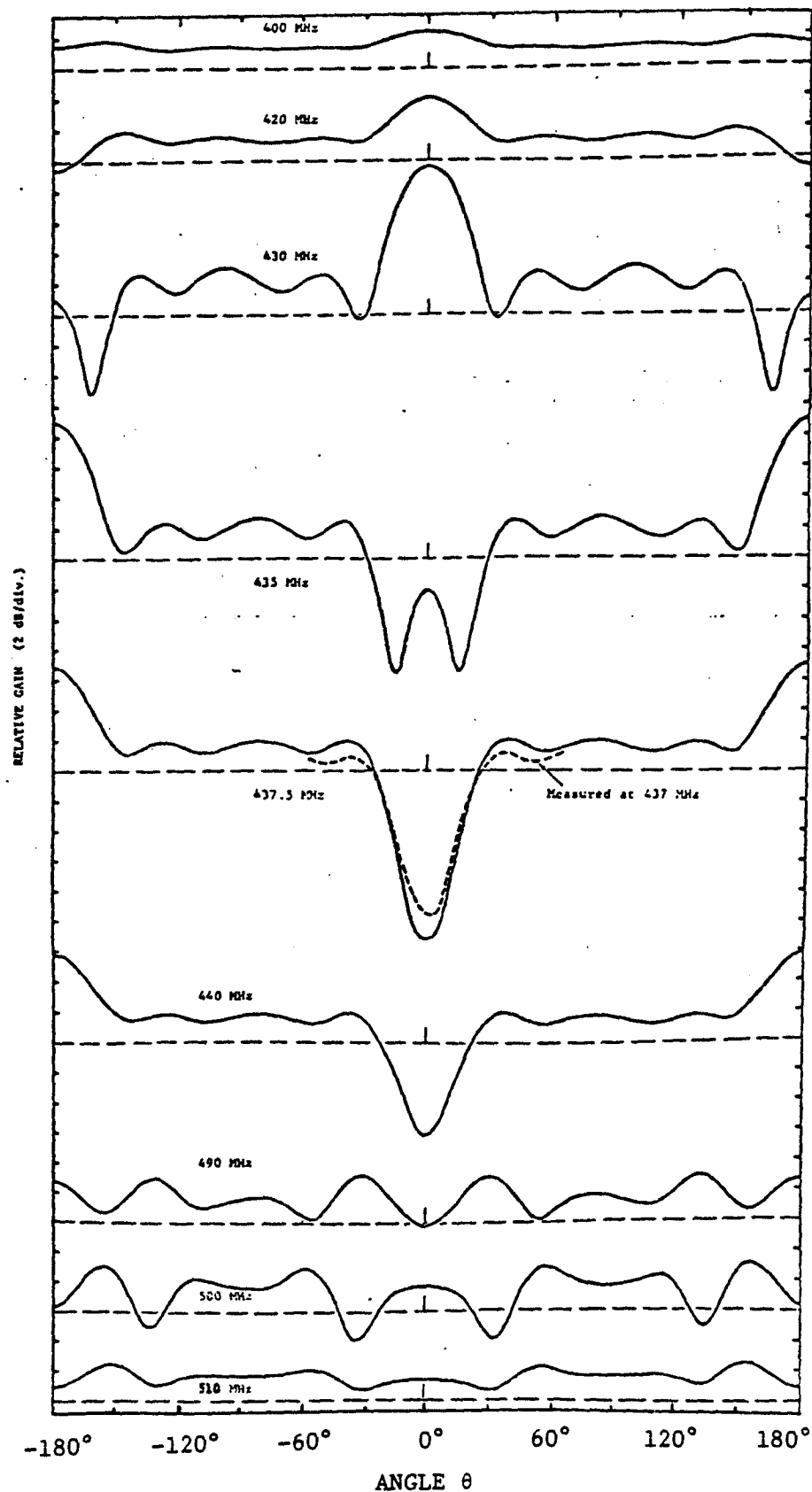point proximity would raise the measured notch level by 2 dB.

FIG. 3 Calculated radiation patterns for the five-tower power line for a distance d'=0.8 m between the line and the antenna. Note the correction for observation-point proximity would raise the measured notch level by 2 dB. Note also that the dashed lines give the 0 dBi gain level reference for each pattern.

AM BROADCAST RE-RADIATION FROM BUILDINGS AND POWER LINES

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ABSTRACT

Experiments and numerical calculations are described for model build-
ings and power lines built approximately to a 1:1000 scale and lo-
cated near a directive transmitting antenna. Both types of model
re-radiate significantly, causing main lobe notching and null-filling
in the radiation pattern of the transmitting antenna. A pair of high-
rise buildings over a highly-conducting ground is shown to exhibit
a pronounced resonance phenomenon not present for a single building,
resulting in null-filling to a level 20 dB below the main lobe and
1 dB main lobe notching for approximately quarter-wave-height build-
ings located 7.5 wavelengths from the transmitting antenna. A res-
onant EHV power line (one wavelength circumference including image)
is shown to produce a pattern perturbation of the same order of
magnitude.

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INTRODUCTION

Existing AM broadcast antenna sites are being encroached upon more and more by large man-made structures such as high-rise buildings, smoke stacks and power lines, and new antenna sites are almost inevitably close to such structures. The broadcasters, their consultants and government regulatory agencies are in many cases greatly concerned about the strength of re-radiation (or scattering) from these structures and the possibility that the re-radiated signal strength will be great enough to fill in radiation pattern nulls designed to protect the coverage areas of distant co-channel or adjacent-channel services.

This work describes experimental measurements and theoretical calculations on the re-radiation from model high-rise buildings and power lines, both constructed approximately using a 1:1000 nominal scale factor.

MODEL HIGH-RISE BUILDINGS

The experimental arrangement of Figure 1 was set up in an anechoic chamber. Figure 2 shows typical swept-frequency measurements of transmitted signal strength between the two antennas. For $\alpha = 0°$, the two buildings behave like a single thicker one, exhibiting a just-discernible resonance near 700 MHz, somewhat below the frequency at which the height is a quarter-wavelength. For $\alpha = 90°$ there appears a new stronger resonance, tentatively interpreted as one involving the "transmission-line" mode between the two buildings. Figure 3 shows polar patterns indicating that the problem consists not just of back-lobe null-filling but also of strong front-lobe notching.

There is a simple relationship between the main lobe notch depth N and the scattered signal or null-fill level S, both expressed in dB relative to the main lobe level. It is straightforward to show that this relationship is

$$S = 20 \log_{10}(1-10^{N/20}) \qquad (1)$$

and that it is unchanged by interchanging S and N. Equation (1) was employed in Figure 4 which shows that a pair of resonant-height buildings could in some cases produce an objectionable effect even if located 10 km from a directional broadcast array.

Moment-method computational techniques[*] were employed, representing each building as a single, thin wire. The calculations produced maximum pattern notch depths within 1 dB of those measured, but the calculations also produced a resonance bandwidth too narrow by a factor of about two, a result undoubtedly due to the use of too thin a representation for the buildings.

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[*]Richmond, J.H., 1974, "Radiation and scattering by thin-wire structures in the complex frequency domain," NASA report CR-2396.

MODEL POWER LINES

Figure 5 shows the experimental arrangement, including the two basic configurations tested. The 9-tower configuration exhibited only one phenomenon substantially different from the other model, namely the reflection of a strong signal in the direction of specular reflection off the line of towers. The 5-tower configuration is a 1:1000 approximate scale model of an existing 500 kV line presently under construction near Toronto and passing within 0.5 km of an existing single-tower AM broadcast antenna. It should be noted that the power line can be thought of as a series of cells, each consisting of two adjacent towers and the lightning arrestor "skywire" joining their tops. To a first approximation, each cell should be resonant at those frequencies where the cell perimeter is an integral number of wavelengths, namely 413, 826, 1240 and 1653 MHz (kHz at full scale).

Figure 6(a) is a measured worst-case radiation pattern for a model with two skywires "grounded" to the tops of all towers and two lower-level wires resistively terminated to represent power-carrying wires. This worst case occurs at a frequency 6% above the estimated first resonance and it shows strong front-lobe notching and back-lobe null-filling. This pattern perturbation was shifted in frequency and reduced slightly in magnitude by isolating the center tower from the skywires as shown in Figure 6(b). However, the swept-frequency measurements of Figure 7 show that the procedure of tower isolation has introduced a new, strong resonance at 700 MHz, and therefore such a curative procedure must be employed with caution. It was found that the power-carrying wires diminish the effect of this new resonance, reducing the scattered field level by as much as 3 or 4 dB in some cases; however the power-carrying wires have little effect on the resonances existing with all towers grounded. Figure 8 displays worst-case distance-variation graphs employing the same correction factors as used for buildings.

Moment-method piecewise-sinusoidal-current thin-wire computational techniques were used to set up a 44-segment computer model of the 5-tower power line, and some results for current distribution and far field are shown in Figures 9 and 10. As in the measurements, the computations show strong primary and secondary resonances near the nominal first resonance frequency, along with weaker effects near the nominal second resonance frequency.
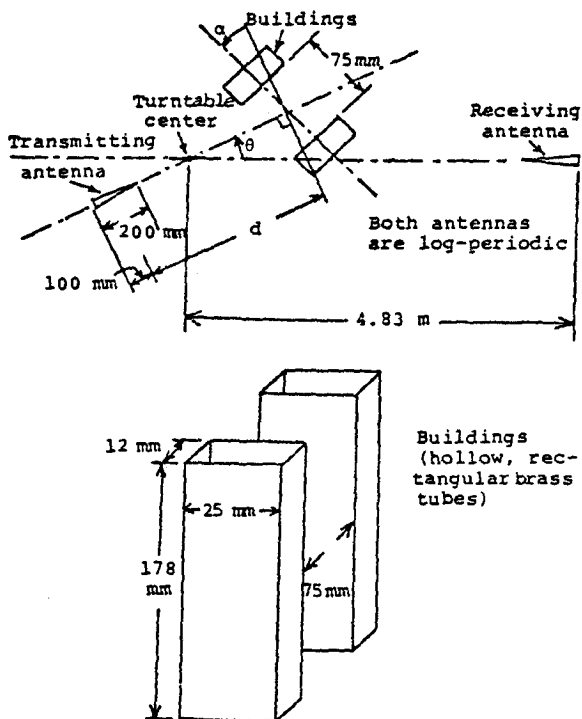
ACKNOWLEDGMENTS

Figure 1 Top view and sketch of experiment
with model buildings. Model includes images,
implying perfectly-conducting ground.
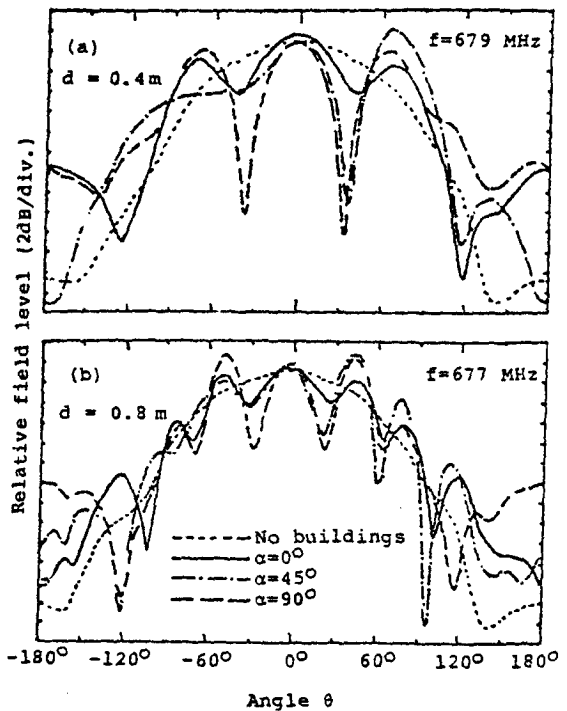
Buildings
(hollow, rec-
tangular brass
tubes)

Figure 3 Worst-case model building radiation
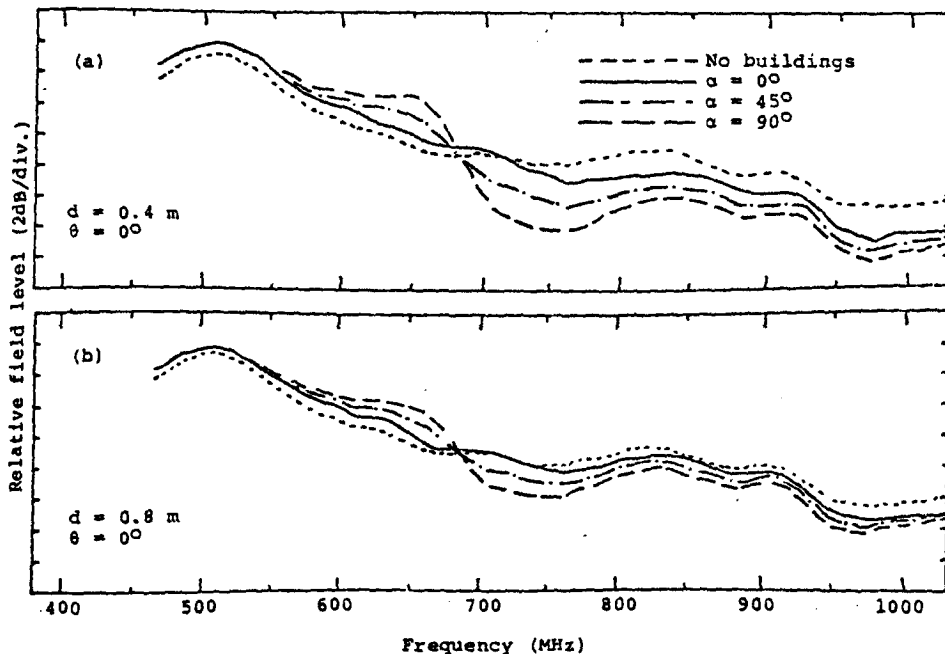pattern measurements at two distances d.

Figure 2 Swept-frequency measurements of transmitted (incident plus re-radiated) signal level
at two distances d between the model buildings and the transmitting antenna.
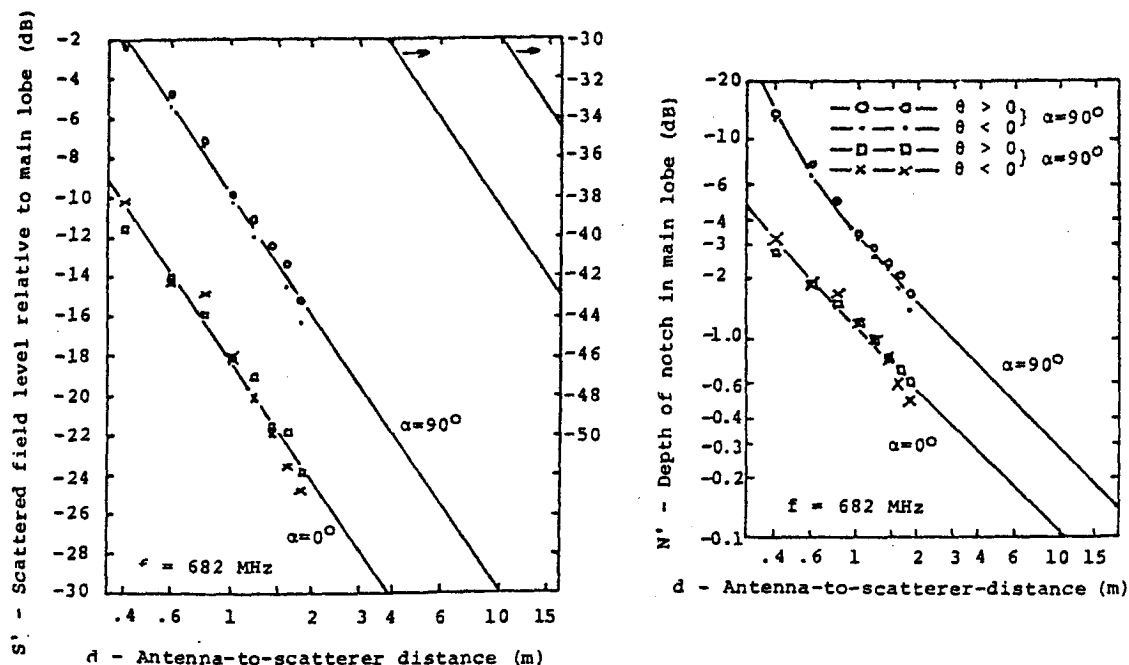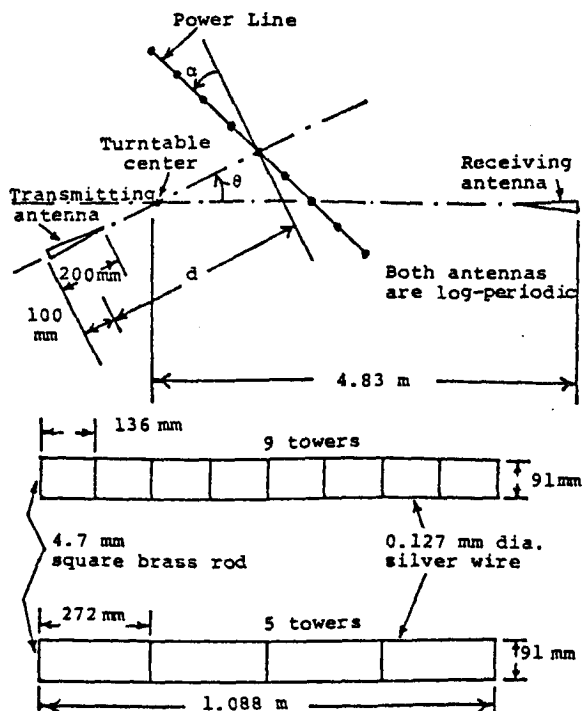
Figure 4 Scattered signal level and notch depth as functions of distance d between model buildings and transmitting antenna. The quantities S'and N' are S and N corrected for a receiving antenna at infinite distance.

Figure 5 Top view and sketch of experiment with model power line. Model includes images, implying perfectly-conducting ground.
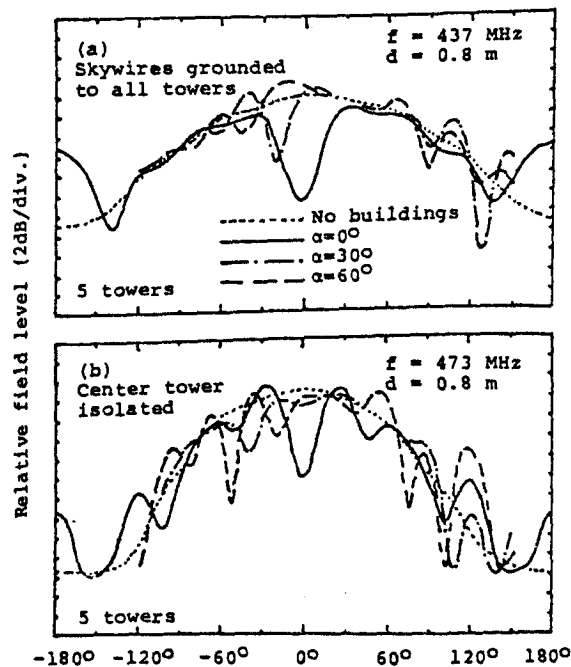
Figure 6 Worst-case model power line radiation patterns showing effect on main resonance of isolating one tower from skywires.
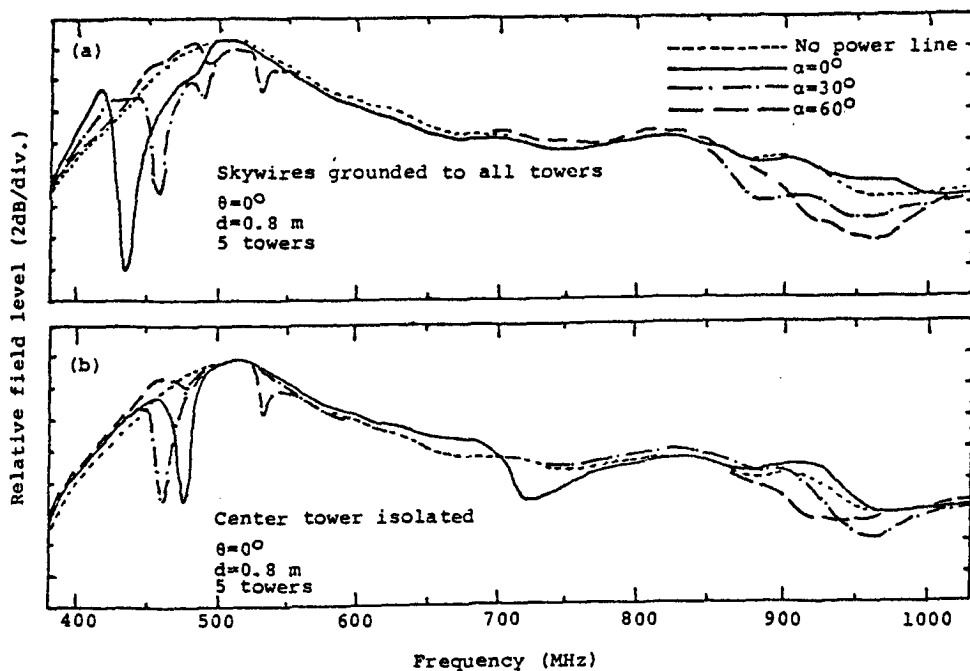
Figure 7 Swept-frequency measurement of transmitted (incident plus re-radiated) signal level for power line with skywires grounded to all towers (a), and with the center tower isolated (b). The tower line carries two skywires and two resistively terminated power-carrying wires.
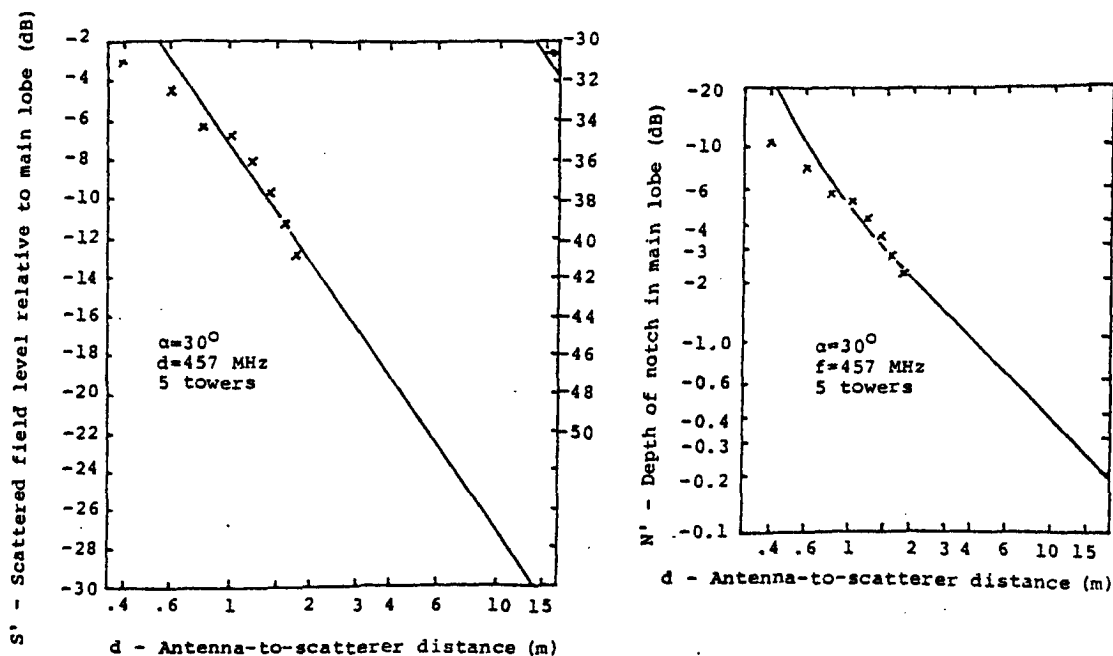

Figure 8 Scattered signal level and notch depth as functions of distance d between the power line and the transmitting antenna. The quantities S' and N' are S and N corrected for a receiving antenna at infinite distance.
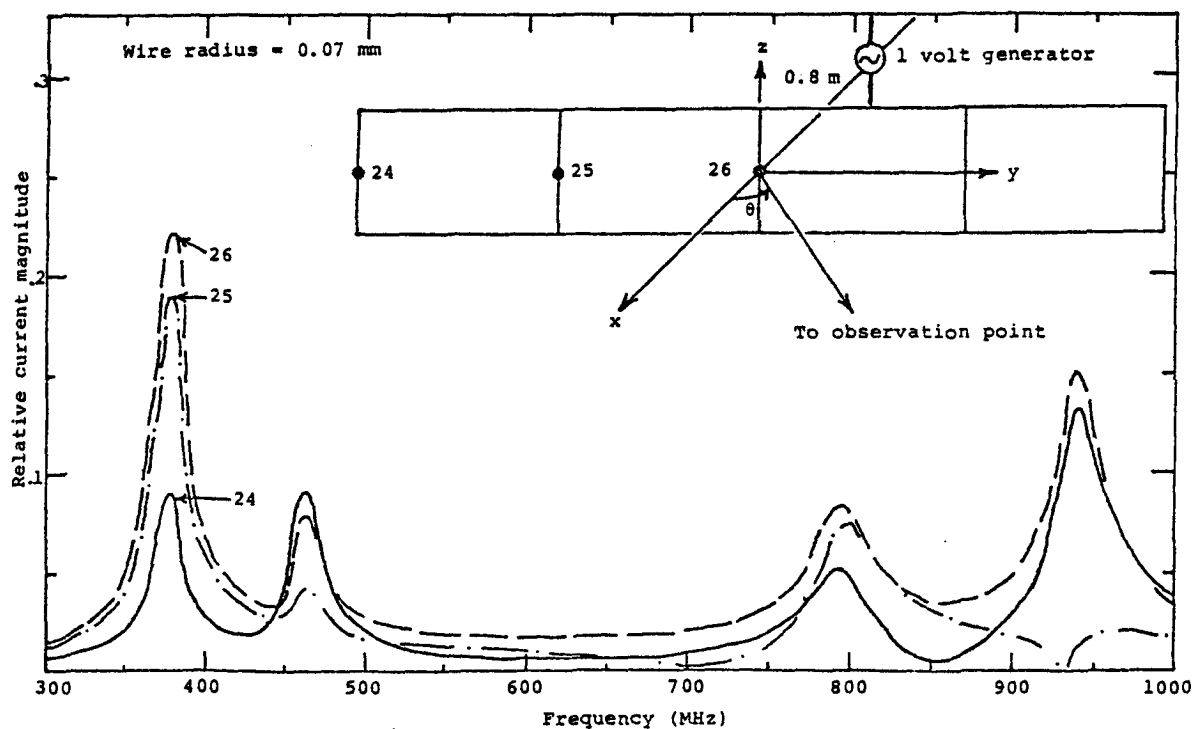
Figure 9 The computer model with calculated current magnitudes at the indicated points (that is, at the bases of the indicated towers). The transmitting antenna height above "ground" is 120 cm, and the power line dimensions are as given in Figure 5 for the 5-tower line.
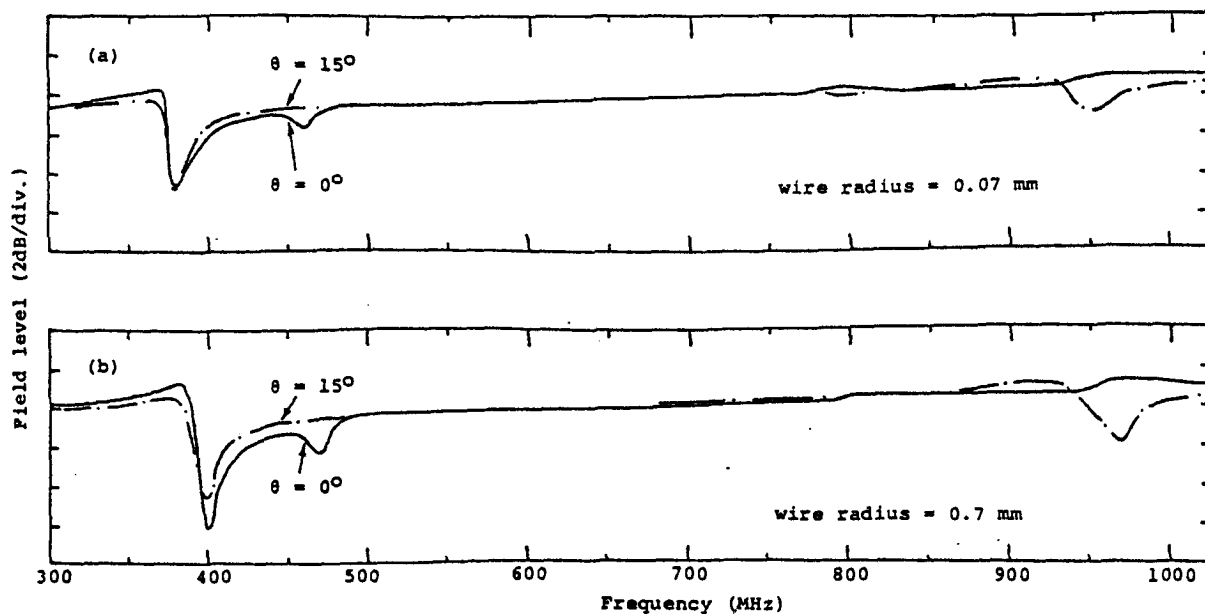

Figure 10 Swept-frequency calculation of transmitted signal level for two different wire radii, using the computer model of Figure 9.

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