1/ Belrose, J. S./

INTERIM REPORT/ NO. 1

2/ THE EFFECTS OF RE-RADIATION

FROM

HIGHRISE BUILDINGS, TRANSMISSION LINES, TOWERS AND OTHER STRUCTURES

UPON AM BROADCASTING DIRECTIONAL ARRAYS



October 26, 1977

# INTERIM REPORT NO. 1

The Effects of Re-Radiation from High-Rise Buildings, Transmission Lines, Towers and Other Structures Upon Directional AM Broadcast Antennae

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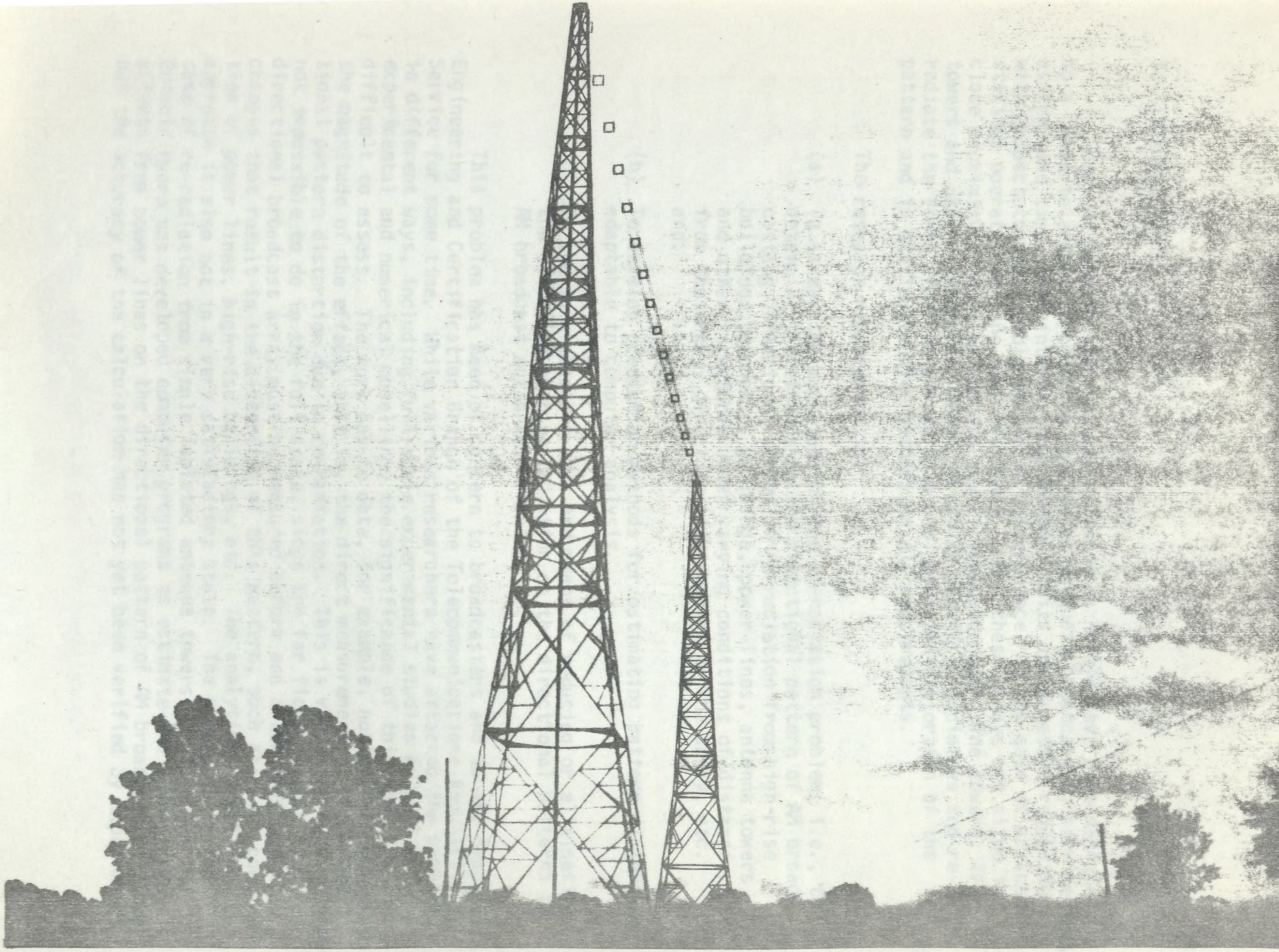

Scale Model of a 300 Foot Grounded-Base L-Type Radiator, Towers Spaced 600 Feet (Tower Height 24 inches)

## 1. INTRODUCTION

Many AM Broadcasting Directional Antenna Arrays have been designed to a close tolerance in order to provide an adequate broadcasting service and, at the same time, meet international treaty limits and domestic regulations with respect to permissible levels of interference, in the case of adjacent stations operating on the same frequency. When these arrays are sited in close proximity to tall buildings, power lines and power line towers, TV towers and other structures, that can act as parasitic radiators and re-radiate the field from the array, this can result in distortion of the pattern and in difficulty with satisfying all requirements.

The research requirement is:

(a) To assess the magnitude of the re-radiation problem, i.e., to determine the effects on the directional pattern of AM broadcasting directional arrays of re-radiation from high-rise buildings, groups of buildings, power lines, antenna towers, and other structures under varying conditions of distance from the array, direction with respect to the array, etc. and;

(b) To develop prediction methods for estimating pattern distortion adaptable to computer analysis.

(c) To evaluate possible ways and means of reducing or eliminating the effect of such re-radiation on the directional patterns of AM broadcast antennae.

This problem has been of concern to broadcasters and to the Broadcast Engineering and Certification Branch of the Telecommunications Regularity Service for some time. While various researchers have attacked the problem in different ways, including full-scale experimental studies as well as experimental and numerical modelling, the significance of this work is difficult to assess. The work has to date, for example, not even established the magnitude of the effect, that is, the direct measurement of the directional pattern distortion due to re-radiation. This is very difficult although not impossible to do in the full scale, since the far field pattern of a directional broadcast array must be measured before and after environmental changes that result in the distortion of this pattern, such as: the construction of power lines, high-rise buildings, etc. The analytical modelling approach is also not in a very satisfactory state. The exception is the case of re-radiation from single isolated antenna towers ... although the Ontario Hydro has developed computer programs to estimate the re-radiation effects from power lines on the directional pattern of AM broadcast stations but the accuracy of the calculation has not yet been verified by experiment.

The particular work is readdressed later in this report. Re-radiation effects from tall buildings and power lines are difficult to treat analytically. If the problem were simple, it would already have been solved. Calculations based on radio wave scattering theory and experiment are not easily related to the basic problem which is pattern distortion in the far field, since re-radiators of concern behave more like parasitic antennae than as scatterers, yet this approach seems to have been almost exclusively used (c.f. Presthold of A.D. Ring & Associates).

Why is the problem so difficult? The answer is simple. Ordinary antenna theory considers radiation from antenna elements or surfaces which are either directly driven or parasitically excited, but such elements or re-radiating structures are in the near field of the radiator and their radiation directly affects or controls the main beam of directional pattern. In the problem at hand, the re-radiation is of secondary importance insofar as the antenna engineer is concerned since the effect is one of "filling in" of the nulls of the antenna array by re-radiation from structures that are not in the near field of the radiator (but are several wave lengths distant ). However, such re-radiation effects are of primary concern to the broadcaster since the null of the pattern is of prime importance to protect adjacent broadcasters who are using the same frequency. In many situations the required null is not in a particular discrete direction but over an angular sector and the magnitude is impossibly great (up to 40 db of attenuation). It is no wonder that the broadcasters are experiencing difficulties with obtaining and maintaining such a directional pattern. It is also pertinent to note that the vertical polar pattern is not considered, yet broadcast station interference is most severe at night when the sky wave is strong and the reception of distance stations particularly troublesome.

## 2. BACKGROUND LEADING UP TO PROJECT

While, as noted above, the problem of AM re-radiation has been of concern to the Department and to the broadcasters for a number of years, until the present project, no research has been carried out (or funded by) the Research Branch in this area. On February 26, 1976, a delegation from the Canadian Association of Broadcasters (CAB) headed by its President, Dr. Pierre Camu, met with DOC to present a brief dealing with the problems of re-radiation as it affects AM broadcasting.

From the recommendations contained in this brief and subsequent discussions at the meeting, a Working Group was formed to investigate the problem in depth with representatives from the following:

- Department of Communications (DOC) (Chairmanship)
- Ministry of State for Urban Affairs (MUA)
- Canadian Radio-Television and Telecommunications Commission (CRTC)
- Canadian Broadcasting Corporation (CBC)

- Canadian Association of Broadcasters (CAB)
- Canadian Electrical Association (CEA)
- Canadian Association of Broadcast Consultants (CABC)

Terms of reference and a Work Plan were adopted at the first meeting of this Working Group chaired by G. Courtemanche (DBC) on September 15, 1976. During three subsequent meetings and extensive investigations by the Working Group, it was established that very little information was available on the technical criteria to predict and prevent costly interference problems caused by the re-radiation of AM signals from obstructing structures. A technical Sub-Group of the members was formed which drafted specific terms of reference for a study of these problems. At the same time, an unsolicited proposal to undertake modelling studies and to carry out full-scale measurements was received from Professor K. Balmain of the University of Toronto. In addition, an up-dated proposal, submitted previously by Dr. J.S. Belrose of CRC as a research project, was also received.

After much discussion and review in the technical Sub-Group, the two proposals were modified and merged together. The present research project, with abreviated title "Re-Radiation Problems in AM Broadcasting", was undertaken by the Research Branch of the DOC in July, 1977. This is the first interim report prepared for the fifth meeting of the Working Group on Re-Radiation Problems in AM Broadcasting scheduled for October 26, 1977.

While the main body of this report describes the experimental and analytical approaches taken, a summary of progress to date and as well, indicates further work this fiscal year, the main content of the document is contained in the appendices which include the NRC Interim Report (Appendix IV) and the University of Toronto Interim Report (Appendix V).

## 3. THE APPROACHES TAKEN

The project as envisaged covers a wide range of theoretical and experimental activities, the work extending over a three year timeframe. The work during the first year would be exploratory, to investigate the feasibility of modelling, both experimental and theoretical, the possibility of developing predictive methods and to decide on the best approach for more detailed work. In the second year, a more elaborate antenna model range would be constructed if the work indicated that this was the right approach and, additional measurements of the base impedance of radiating structures and of the current (amplitude and phase) induced in such structures, would be measured. In the third year, more detailed experiments would be done, to develop, if possible, experimental techniques to determine the influence of lossy ground and lossy and inhomogeneous architectural media and, to investigate ways and means of reducing or eliminating the effects of such re-radiation on the directional patterns of AM broadcast antennae.

Analytical modelling would be a large part of the research and, in fact, the raison d'être for the work. And finally, to evaluate the various preventive methods by field testing (through contract and with the co-operation of the CAE and the broadcasters and their consultants) to confirm modelling results in full scale.

In order to appreciate the thrust of the work, the project objectives are summarized below:

(a) To assess the magnitude of the re-radiation problem, i.e., to determine the effects on the directional pattern of AM broadcasting directional arrays of re-radiation from high-rise buildings, groups of buildings, power lines, antenna towers and other structures under varying conditions of distance from the array, direction with respect to the array, etc, employing initially the NRC antenna modelling range (known as the Ship Range). An AM broadcast array and re-radiating structures will be modelled to an appropriate scale factor and, the directional pattern will be measured with and without re-radiators. While the frequency employed for these model studies need not be invariable, it will be chosen appropriate to the situation under study (e.g., re-radiation from buildings or power lines), for a particular experiment the frequency is fixed.

(b) To investigate particular situations that can result from a resonance involving height and/or spacing of re-radiating structures so that these can be modelled on the NRC antenna model range to determine the effect on pattern distortion, by employing swept frequency techniques, as developed by Prof. K. Balmain and employing the radio anechoic chamber at the University of Toronto. While this aspect of the work is very important and it complements well that carried out by the NRC team, it is expected that the University of Toronto work will provide additional insight in various aspects of the re-radiated fields and so, the work should stand on its own insofar as contributing to our understanding of the problem.

(c) To support these experimental studies by analytical model studies, with the end view being the development of predictive methods for assessing pattern distortion adaptable to computer analysis.

(d) To investigate possible ways and means of reducing or eliminating the effects of re-radiation, to evaluate preventive methods and to carry out field testing to confirm modelling results in full scale.

While this modelling method seems to be the direct and obvious way to measure the magnitude of the re-radiation effect and to investigate ways and means of eliminating it, curiously, this approach does not seem to have been tried by other researchers concerned with the problem. For example, the only modelling work that we are aware of is that of Alford and French (1966) who modelled a power line, employing a frequency of about 962 MHz and a ground plane 8 X 4 feet (equivalent to 7700 X 3850 feet). They excited the power line by coupling radio frequency energy into one of the eight towers. Since they were using the line of towers as the radiating structure, naturally they got radiation from it and when they tried to detune it, naturally they could affect the radiated field ... but this does not easily relate to the problem at hand. Namely, if a broadcast antenna array has a certain directional pattern, how is this pattern affected by the presence of re-radiating structures? Experiments conducted at full scale are difficult to interpret since it is almost impossible to isolate the direct and re-radiated fields, nor is it possible, except in particular situations (e.g., the present series of measurements being made on the pattern of CBL/CJBC Toronto), to make measurements without and with re-radiators.

## 4. PROGRESS TO DATE

In spite of the late formal approval for this project by senior management (first week of September, 1977), the milestones (see Section 5 of this interim report) have been met. This was possible since planning for the project had begun at least nine months earlier (December, 1976) and acting on the authority of the Director General Telecommunications Services memorandum dated 29 June, 1977 which stated that funds could be made available to begin work on the project in this Fiscal Year, a measurement program at NRC was begun in July 1977. The interim report on this work is attached (Appendix IV). Due to various delays, the contract for the work to be carried out at the University of Toronto was not let until October, 1977; nevertheless, some initial work has already been done (Appendix V).

The first decision to be made concerned the antenna array to be used in the tests. The primary criteria was that the array be simple to model and that the pattern have a null that was at least 40 db deep. As the main intent of the tests is to see the effect of buildings, etc, on the null portion of an antenna pattern, any method that produces a null is valid and we might as well use the easiest. While these considerations are briefly discussed further in Appendix I, the decision made was to employ two towers, 180 degrees apart and fed in phase. In this arrangement, all that is required is that the towers be identical and the two feed cables from the power splitter be identical ... no matching is required and no restrictions on cable impedance are present. The resultant figure 8 pattern was, in fact, almost ideal (see Appendix IV, Figure 1) and is more than adequate for the initial investigations.

As for building sizes and heights (see discussion in Appendix II), it was decided that the initial measurements would be made for buildings having a fixed cross-sectional area but variable height. In fact, scale model buildings were constructed for a square building 100 feet on its side and heights ranging from 50 to 400 feet. Employing a modelling frequency of 300 MHz, this corresponds to scale model buildings which were 2 inches square and heights ranging from 4 to 16 inches.

Initial measurements were made to examine the surface impedance effect for buildings just sitting on the ground plane. Because of the appreciable physical dimensions and the frequency employed, it was found that the capacity of the building to the ground plane was sufficient to simulate the building being physically bonded to the ground plane.

The details of the results obtained are contained in the NRC interim report (Appendix IV) but briefly, the findings were as follows. The effect is largest (as expected) when the building height is such that it is approximately resonant (or height > resonant height) and it appears that single buildings can be treated theoretically as fat monopoles; i.e., the scatter signal into the null can (presumably) be calculated by taking into account the incident field strength from the AM array and assuming that the re-radiated signal is omni-directional. A discussion of the initial tests that were proposed is included in Appendix III. Many of these measurements have been made but for brevity are not included here.

A number of measurements were also made for power lines, with and without sky-wires. A large number of patterns were obtained and these were more difficult to analyze. Curiously, patterns obtained with top wires were notably cleaner than without a top wire; and initial investigations relevant to spacing of power line towers revealed that 500 foot spacing (½ wavelength spacing) produces less scatter than 1000 foot spacing ($\lambda$ spacing). Transmission lines contain many more variables and at the moment, the patterns obtained do not readily suggest a method for predicting the scatter.

It is shown, however, that the NCR "Ship Range" facility is more than adequate to detect and measure signals re-radiated from scale model buildings and power lines. Full scale distances up to a mile have been used. The scatter signal into the null is as large as -17 db with respect to main beam which is large compared with the null signal that is -40 db in the absence of re-radiation. This scattered signal is however small compared with the principle pattern signal, although scalloping of the main beam by ± 1 or 2 db is clearly evident. These measurements cast doubt on the possibility that the CBL/CJBC Hornby measurements made for an omni-directional array will reveal anything useful, since, if the scatter field is at most ± 10 percent of the omni-directional field strength, the scalloping will only be ± 1 db or so, which is the same order of magnitude as the uncertainty of measurement. The effect could be more pronounced if by chance the power-line were resonant, or approximately resonant for one of the two operating frequencies (this is addressed below). The initial measurements by NRC on power lines are believed to be for situations where the power-line and its sky wire are not resonant at the scale frequency employed for the tests.

The University of Toronto measurements, (Appendix V) while very interesting, are more difficult to describe, and visualize since they do not provide directly a measure of pattern distortion. The experimental arrangement utilizes two log-periodic (frequency independent) antenna arrays, one for transmitting and one for receiving located at opposite ends of the anechoic chamber. A model scale factor of 1000 is employed (buildings and power lines are 1/1000 of their full scale size), and therefore for the scale model frequency range 450 to 1050 MHz, this corresponds to full scale frequencies of 450 to 1050 kHz. The re-radiators are placed on an insulated turn-table close to the "model antenna" and the effect is measured in the far field by the "range antenna". Thus different orientations of the scatterer with respect to the plane of propegation can be investigated. The results provide a measure of the combination of the direct field and the forward scattered field from the re-radiator. Thus as the frequency is swept, maxima and minima in field strength can be observed which is the interference pattern between these two vectors. Resonant situations can be observed at frequencies where the interference effects are particularly strong. The measurements are made "in free space", i.e. no ground plane is employed. Therefore the building sizes (heights) must all be twice those for grounded buildings, and the power lines towers are twice the height of actual towers with sky wires (if connected), at the top and bottom of the towers. Thus the model represents a perfectly conducting ground plane.

While the initial investigations that have been made, particularly those relating to the effects of buildings, are for strong scatter situations (buildings are located close the antenna array), it is clear that (1) the scatter field can be measured in these sweep frequency experiments, and (2) that resonant situations can be detected. The re-radiation from pairs of high-rise buildings has been investigated, and the results indicate that re-radiation from groups of buildings may be strong, and that peculiar re-radiation effects are present even if the high-rise towers are rather widely separated. The measurements for power-lines reveal very clearly resonant situations when the interference field is strong. The magnitude of the scatter or interference field of ± 1 db or less in the non-resonant situation is representative of a null field (db below maximum field) of -20 db or less, which is of the same order as measured on the NRC range.

While studies by analytical modelling have not started, nor at this early stage of the research has there been any investigation of possible ways and means of reducing the effects of re-radiation (such work is planned to be carried in 1978 or 1979), three items should be made note of in this interim report. In June, 1977 we received a copy of the report by D.E. Jones, of the Research Division, Ontario Hydro, on "Modelling a Power Line as a Parasitic Antenna Array", and we were asked to comment on the approach taken. For reasons detailed in Appendix VI we do not believe that the method correctly depicts the re-radiation from power-lines with connected sky-wires.

At this stage of our work we are not in a position to propose in detail alternative simulation methods. The basic objection that we have with the method that Jones has developed concerns the way in which impedances and currents (flowing in the towers and along the sky-wires) are combined. The base impedance of the insulated towers and the Thevenin impedance seen "looking back along the sky-wires", cannot be combined as though they were "lumped series impedances". More corrected the power line must be analysed as (1) a multi-tuned top-loaded vertical radiator system; or (2) a system of coupled loops, each loop being that formed by a particular tower, the connecting sky wire to the next tower, the adjacent tower, and the ground return path between towers. While the latter seems like a good approach, the author of this interim report better understands the former. Since each tower in the line of towers can be considered as a grounded vertical radiator, top-loaded by twice the capacity of one-half the span between each tower, i.e. a T-type radiator, the resonant frequency of the system can be quite easily (approximately) estimated and, employing this concept a method to detune the transmission line clearly suggests itself (Appendices VII and VIII). For the CBL/CJBC situation comprising 165 foot towers spaced 900 feet, we deduce that the fundamental frequency (quarter wave resonance) would be less than 500 kHz) about 400 kHz. However half wave resonance will occur at a frequency that is somewhat less than twice this frequency, which suggests that if re-radiation effects are measureable for this omni-directional array they should be more pronounced for the higher frequency (CJBC transmits on 860 kHz, CBL on 740 kHz). Obviously if more work is done for this particular situation we need to better analytically simulate the real situation, and to better model the towers and their connecting sky-wires.

Finally, Appendix VIII outlines a method that could be employed to actually measure the impedance of power-lines, a method that has not to our knowledge be applied. And also this method leads directly to a method for detuning the power line lowering the resonant frequency of the system so that the fundemental frequency and multiples of it lie below the operating frequency of the AM broadcast station.

## 5. FURTHER WORK THIS FISCAL YEAR

Since the NRC antenna range is a fair weather range, it can be used for only 2-3 weeks more this fall. The University of Toronto work can of course, and will, be carried out without interuption by winter weather. Measurements have already been started employing the NRC range to investigate the effect of two-buildings and, probably, further investigations for power-lines that are resonant will not be carried, but maybe, not before next spring. More realistic power-line models will likely be constructed during the winter months for measurements on the NRC range next spring.

Obviously the purpose of this interim report is to stimulate feed-back from the members of the Working Group and their associates. And this feed-back could of course alter the direction of the work. The two interim reports by NRC researchers (W. Lavrench) and University of Toronto researchers (Prof. K.G. Balmain) include only a few of the scores of polar-diagrams and graphs that have already been amassed.

The projected milestones for this project for the remainder of this fiscal-year follow.

PROJECT 15010

Re-Radiation Problems in AM Broadcasting

Milestones for FY 77/78

Second Quarter

To initiate a measurement program employing the NRC antenna modelling range (known as the Ship Range Facility) to evaluate the magnitude of the re-radiation effects for high-rise buildings and power-lines with varying distance and bearing from the AM broadcast array; and at the University of Toronto employing swept frequency techniques to gain insight into the properties of the re-radiators.

Third Quarter

To continue investigations as described above.

To begin initial evaluation of the theoretical/computational approach to the problem, from the points of view of accuracy compared to experiments, complexity, mathematical models, etc. The ultimate objective being to predict pattern distortion effects.

Fourth Quarter

To continue work as described above. The investigations as required for the first stage of the work at the University of Toronto are expected to be completed this quarter, but the measurement program at NRC will not be completed before about August, 1978.

A decision is required in 1978 as to whether a new antenna modelling range is required. The new facility would have a larger turn table (100 feet instead of 20 feet), and would be elevated so that measurement equipment could be deployed from beneath the ground screen to measure impedances, currents induced in re-radiating structures, etc. The larger turntable would permit a study of the effect of re-radiators at greater distances from the directional array, and for distances up to one mile in full scale, a smaller scale factor could be employed so that re-radiators, particularly power-lines could be more realistically modelled so as to evaluate preventive methods. The present investigations using the NRC range employed a scale factor of 600 for study of re-radiation from transmission lines. Towerheights of 3.3 inches (167 feet) were employed. For a larger facility, 100 foot diameter turn table compare with 20 foot diameter, the same measurements could be made using a scale model frequency of 120MHz and scale model towers of 19.8 inches. It is cear that with such model towers it will be easier to more realistically model the towers and investigate methods of reducing or eliminating the effects of re-radiation. The figure that is seen as preface to this interim report is a photograph of a 300 foot tower modelled by the author a few years ago. The height of these scale model towers was 24 inches.

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Controlling the Effects of Parasitic Re-Radiation in Directional Antennas, John H. Battison, Carl E. Smith Consulting Radio Engineers (NAB Broadcast Engr. Conference (date unknown) text only available, attached to a letter to A.G. Day from G.W. Bartlett, NAB, d. 17 November 1976).

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APPENDIX I

# Some Preliminary Thoughts on Directional Antenna Array to be Modelled

Carl E. Smith, Directional Antennas, Cleveland Institute of Radio Electronics, Cleveland, Ohio, 1946* is the most extensive publication that I know gives systematic antenna patterns for two or more tower arrays. Obviously, for the present work, we should restrict ourselves to a two-tower array, at least for initial work. The pattern should have a deep null.

The simplest arrangement is two towers, a quarter-wavelength high, spaced 180 degrees apart and fed in phase. In this arrangement, all that is required is that the towers be identical and that the two feed cables from the power splitter be identical. No matching is required and no restrictions on cable impedance are present. The resultant figure 8 pattern should have two very deep nulls which should be adequate for the tests.

Two quarter-wavelength towers, 90 degrees apart and fed in phase quadrature provide a cardiod pattern, with one very deep null and minimum field strengths over a broader sector angle. Such an array is well documented in the literature (c.f. Jordan, Electromagnetic Waves and Radiating Systems, Prentise Hall, pp 519 - 521, 1950 who gives complete design information). However, this antenna array is more difficult to construct and adjust and the adjustments will have to be fairly precise to achieve a null > 40 db down.

For the above reasons, it is concluded that the figure 8 pattern will be quite satisfactory for the initial tests, since the main intent of the tests is to see the effect of buildings, etc, on the null of an antenna array and, therefore, any method of producing a null is valid.

John S. Belrose
15 July 1977

* See also NAB Engineering Handbook, McGraw Hill, 1960, Pt. 3 Standard Broadcast Antenna Studies by C.E. Smith and D.B. Hutton, pp 2-87 to 2-165.

APPENDIX II

## On Building Sizes and Heights

The correspondence by Clive Eastwood, dated May 26, 1972 concerned re-radiation from proposed buildings in the Mississauga area. Dimensions given (infact) were:

| Length | Width | Height |
|---|---|---|
| 258 | 46.5 | 153.5 |
| 258 | 46.5 | 162.0 |
| 220 | 60.0 | 212.0 |
| 112 | 84.0 | 238.0 |

Buildings are typically 12 to 14 feet in height per floor, and buildings of 10 to 30 floors then correspond to physical heights of 130 to 300 feet. There is no particular pattern for dimensional size (length and width). The new Metropolitan Life Building in Ottawa is about 165 x 140 feet, the Chateau Laurier 130 x 560 feet, a city block is 200 feet to 560 feet. Buildings sometimes are grouped in twin-tower arrangements (Journal Towers North and South), often in larger groups.

The AM Broadcast band extends from 535 to 1605 kHz. Mid-band or geometric mean frequency is 925 kHz, which corresponds to a wavelength of 1063 feet or 266 feet is a quarter wave length. There is therefore a real possibility that a high-rise building adjacent or near-by to an AM broadcast station could be quarter wave resonant at the frequency of the station. For a building having a floor area of 12,000 $ft^2$, the equivalent circular dimension is 123 feet diameter, which is $42^o$ (electrical degrees). The work of Brown and Woodward (1945)* considered radiators up to $10^o$ diameter. If one extrapolates their data to $40^o$, the electrical length for quarter wave resonance is estimated to be $75^o$. Hence a building 75/90 (266) = 221 feet high would be quarter wave resonant at 925 kHz (9.5 inches at 300 MHz).

It is suggested that initial measurements be made for buildings having a constant cross-sectional dimension 100 feet on a side (4 inches on a side at 300 MHz) and that measurements be made for heights 50 to 400 feet (2 to 16 inches at 300 MHz).

John S. Belrose
15 July, 1977

*Brown G.H. and O.M. Woodward, Experimentally determined impedance characteristics of cyclindrical antenna, Proc. IRE, 33, 287, April 1945.

## Proposed Initial Measurement Program, Employing NRC Modelling Range, to Study the Effect of High-Rise Buildings

### Introduction

This memorandum which summarizes our initial thoughts on the above subject is based on my letter of July 15, 1977, file 6560-9 to J.Y. Wong and his reply (both letters are attached) and on discussions I had with W. Lavrench, NRC antenna engineer assigned to the task on August 3, 1977. For completness the following paragraph summarizes briefly parameters and configuration of the NRC antenna modelling range.

### The NRC Antenna Modelling Range (referred to by then as the "Ship Range")

This range comprises a wire grid (1-inch mesh) on a flat asphalt surface 198 feet by 70 feet at ground level. A 20 foot diameter turn table, flush with the surface of the ground plane is located 58 feet (to its centre) from one end of the range. The AM transmitting antenna will be centrally mounted on this turn table. The receiving antenna is a corner reflector, designed to illuminate the range, located at the opposite end of the ground plane, about 138 feet from the centre of the turn table. A rotatable boom is arranged so that it can be swung over the centre of the ground-plane, to measure the vertical polar diagram of the antenna being modelled.

A sketch of the antenna modelling range is shown in Figure 1.

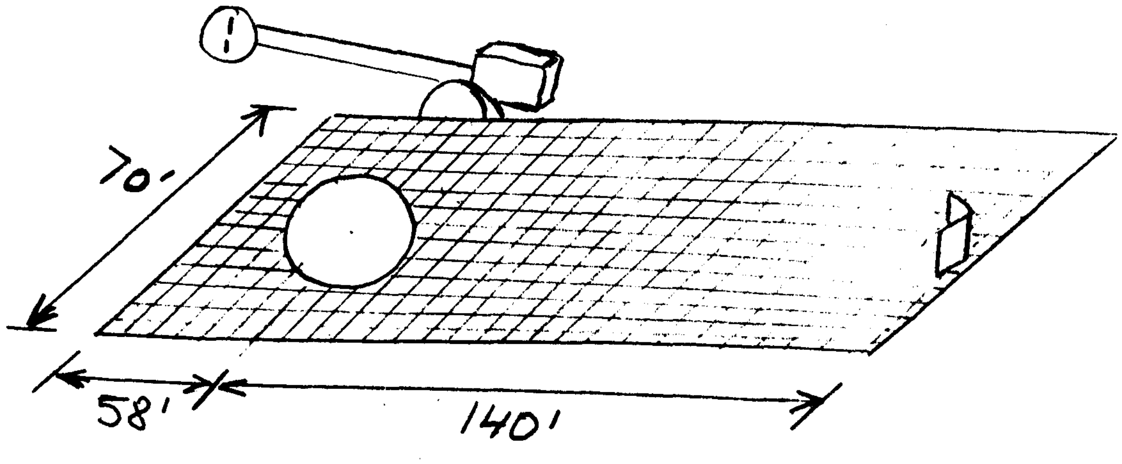


Fig. 1. Sketch of the NRC Antenna Modelling Range.

...2

Geometry Pertinent to the AM Re-Radiation Measurements for Studying Effects of High-Rise Buildings

Let T be the location of the transmitting antenna (the geometric centre of the array); R the location of the receiving antenna which for the present discussion is considered to be in the direction of the null of transmitting array (although in the present situation the transmitting antenna is notatable in azimuth); and P is the location of a parasitically excited re-radiator at distance d (meters) or D (wavelengths) from T. If two or more high-rise buildings are employed we will consider (for the present) only the situation where these are radially located from the transmitting array at distances $D_1$ and $D_2$, etc.

Since it is the far field that is of interest the distance T-R must be very very much greater than T-P, which it is. The distances of concern for re-radiators probably lie in the range $D < 5\lambda$, and for a model frequency of 300 MHz the distance T-R is $42\lambda$. Let $\theta$ be the angle between the plane that contains T and R and the plane that contains T and P. This situation is sketched in Figure 2 below.

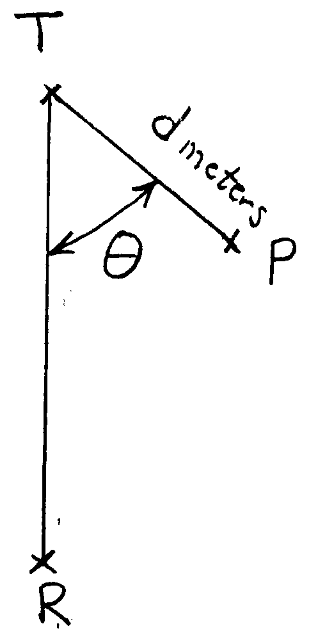


Fig. 2. Geometry for a re-radiator close to the transmitter affecting the signal received at R from a transmitter at T.

Transmitting Antenna Array

The AM antenna array which will be modelled will be two quarter wave towers, spaced $\lambda/2$ apart and fed in phase. In this arrangement all that is required is that the two towers be identical and the two feed cables from the power splitter must be identical (and preferrably a multiple of a half-wave length long taking into account the velocity of propagation in the cable). No matching will be required and no restrictions on cable impedance are present. The towers should be equi-distantly spaced on opposite sides of the centre of the turn-table. The antenna pattern will be a figure 8 which is a pattern that has 180° symmetry, and therefore values of $\theta$ lie between 0 and 180°.

Parameters that are Variable

The various parameters that are variable are:

1) Distance D: useful values probably lie in the range 1 - 5$\lambda$ (1000-5000 feet at broadcast frequencies mid-band). Suggested values of D for single re-radiators are 1, 1.5, 2, 2.5, 3, 4 and 5$\lambda$.

2) Angle to re-radiator $\theta$: values of interest lie in the range 0-180°. Suggested values for $\theta$ are 0°, 30°, 60°, 90°, 120°, 150°, and 180°.

3) Size shape and number of buildings: initially I recommend that we choose a particular building cross-sectional dimension, say 100 feet on a side, which for a frequency of 1000 kHz corresponds to 4 inches on a side at 300 MHz (scaling factor 300); and that five building heights should be modelled corresponding to quarter wave resonance (determined by experiment and ½, 3/4, 1.25 and 1.5 times that height. Concerning experiments with more than one building we might start out with the worst situation, and decide where we go from there; for example with two high-rise buildings of height equivalent to quarter wave resonance, and with building #1 at a particular distance we would vary the position of building #2, in the same radial direction, increments of say one eight wave length over a one wave length separation. We will have to decide later on how best to approach the problem of buildings of various cross-sectional dimensions.

Since radius of the turn-table is 10 feet, this corresponds to a distance of 3$\lambda$ at 300 MHz. Therefore for distances D < 3$\lambda$ both the directional array and the re-radiator can be on the turn-table, which is the best arrangement since as the turn-table is rotated the directional pattern is measured for a re-radiator at a fixed location with respect to the array. For distances D > 3$\lambda$ the re-radiator will not be on the turn-table, unless we could extend the turn-table by employing a temporary arm. Certainly in this situation the data will be more difficult to interpret since as the turn-table is rotated the re-radiator position will effectively change over all possible values of $\theta$ at a fixed distance D.

...4

The measurement program above will require the measurement of: number of buildings X number of values of D X number of values for $\theta = 5 \times 7 \times 7 = 245$ polar diagrams, plus the one diagram for the array without re-radiators; and this is for the situation in which there is only one high-rise building having a fixed cross-section but variable height. We'll have to tailor the measurement program on experience to be gained as the measurements are made.

The question of measurement of the vertical polar diagram has not been discussed above, yet it is the sky-wave field which results in the interference experienced at nighttime. An attempt to measure the vertical polar diagram in the plane of the null (the plane TR) with and without re-radiators should be made, and the decision made as to whether the vertical polar diagram should be measured as a routine.

Measurement of the Resonant Frequency and the Impedance of Modelled Buildings

As previously noted the resonant frequency and impedance of "fat" tower radiators having a diameter of >10° has not been measured (that I know about). A building 100 feet on side has a cross-sectional area that corresponds to a circular radiator of diameter equal to 40°. It will therefore be necessary to measure the resonant frequency and impedance of structures of various cross-sectional/height dimension. The resonant frequency of a modelled grounded high-rise building can be measured by making it into a folded monopole, see Fig. 3(a) below and measuring the input impedance of the monopole. The self-impedance of the structure is more easily measured by employing an insulated base structure. A "building" of zero height (comprising a conducting bottom plate only) would be a capacity, and this capacity subtracted from the measured impedance of a building of height h would give the self-impedance of the structure. When CRC has some in-house staff working on this project (October or November 1977) we will measure the self impedance of various structures, but for the purposes of modelling on the NRC range since only the self-resonance frequency is needed this measurement could be made by them in the course of their modelling measurements.

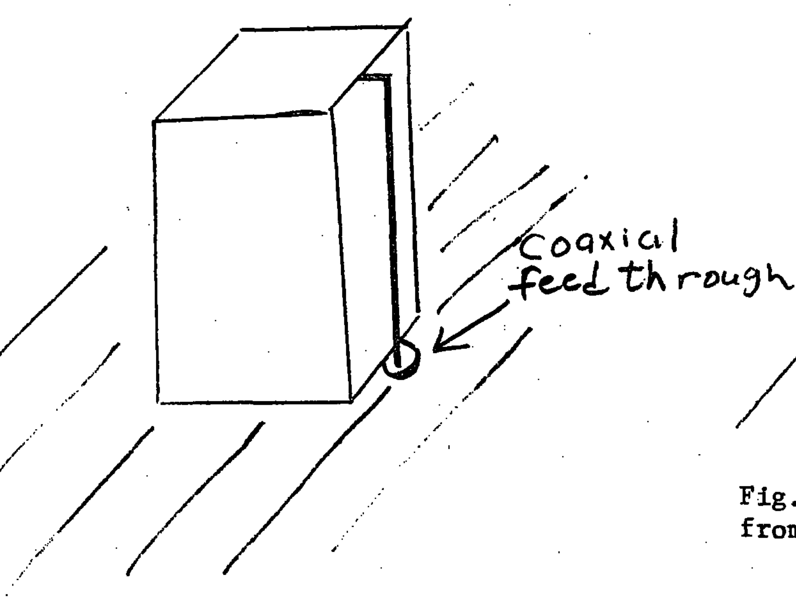


Fig. 3(a). Grounded building arranged as a folded monopole to measure self resonant frequency.

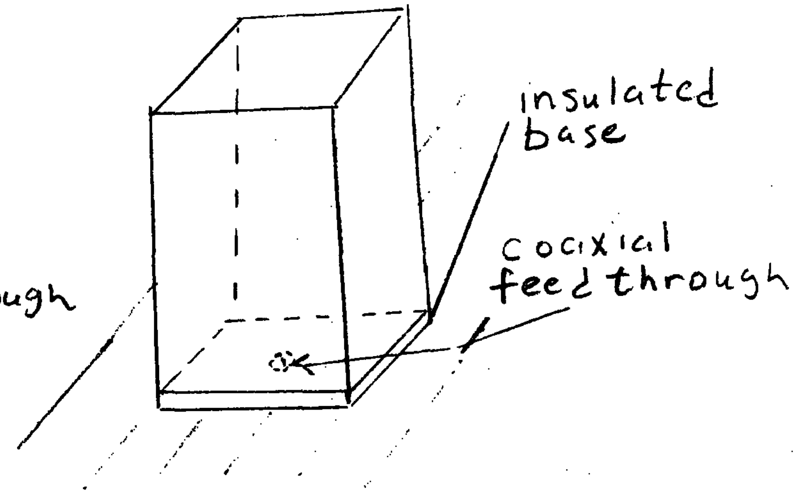


Fig. 3(b). "Grounded" building insulated from ground to measure self impedance.

John S. Belrose
August 11, 1977

APPENDIX IV

## Interim Report on NRC Work

### Introduction

A request to make a study of the effects of re-radiation of AM broadcast signals was received from the Department of Communications in July of 1977.

In brief, this study was initiated for the following reason. AM broadcast stations are in some instances required to protect the coverage of a distant co-channel station. This is done by designing the broadcast array to produce a minimum radiation of specified width and amplitude in the direction of the other station. However, there arise occasions when a tall building or transmission line towers are erected at a later date in the vicinity of the array. These new structures then scatter the broadcast energy in various directions including that of the protected station.

Prior to DOC establishing their own antenna range for scale model studies on this problem, it was decided that some useful preliminary information could be obtained using the NRC Ship Range.

The Ship Range is an outdoor site consisting of a level surface 70 feet wide by 198 feet long. On the center line and 58 feet from one end, there is a flush turntable 20 feet in diameter. The turntable surface is of sheet copper and the remainder of the range is covered with one inch wire mesh.

The procedure used to measure scatter from model buildings and towers consisted of plotting an antenna pattern of the model AM array with no scatterers in the vicinity; then repeating the test with a scatterer. The amount of scatter can be read in that part of the array pattern containing a null.

### Re-Radiation From Buildings

Measurements for this part of the investigation were carried out at a frequency of 300 MHz. This gives a scale factor of 300 relative to a 1 MHz broadcast station. There is nothing "magic" about this scale factor other than it leads to a convenient quarter-wave tower, namely about ten inches high.

The scale model broadcast array consisted of two quarter-wave monopoles, fed in phase and placed half a wavelength apart. This produced a figure of eight pattern with two deep nulls in line with the monopoles and maximum radiation at right angles to the center line. At all times the center of this array was located at the center of the turntable. A typical antenna pattern obtained with no scatterers in the vicinity is shown in Figure 1. It can be seen that the nulls obtained approached -40 db. Calibrations on the pattern are in decibels.

Initial tests were done using a scale model building which was 4 inches square (100 ft x 100 ft). For the convenience of the reader, the figures in brackets indicate here and below the full scale sizes or distances as the case may be.

## Variation of Scatter With Building Height

Building heights ranging from 2 to 16 inches (50 ft to 400 ft) were used. In all cases, the building was located in a maximum portion of the array pattern and 2 meters (2000 ft) from the array.

A plot of the scatter signal versus building height is shown in Figure 2. It can be seen that for building heights greater than 8 inches (200 ft) the scatter is relatively constant. Typical patterns are shown in Figure 3 and Figure 4 for building heights of 8 inches (200 ft) and 12 inches (300 ft). The patterns are almost similar.

As an aside, a similar series of patterns was plotted for a thin monopole - 1/10 inch (2½ ft) in diameter. These results also appear in Figure 2. The pattern for the resonant height - 9½ inches (237.5 ft) is shown in Figure 5. This pattern is very similar to that obtained with the 8 inch (200 ft) building.

It may be of interest to see how this scatter compares with a calculated value for resonant antennae. In the case of two coupled half-wave antennae, the current $I_2$ induced in the second antenna by a current $I_1$ flowing in the first is given by

$$I_2 = -I_1 \frac{Z_M}{Z_2}$$

Where $Z_2$ is the self impedance of the second antenna and

$Z_M$ is the mutual impedance between the two antennae.

For a resonant half-wave dipole, the self impedance is 73 ohms. The mutual impedance of two antennae 2 wavelengths apart is 1 + j10 ohms - Antennas, J.D. Kraus, p. 266.

The ratio of $|Z_M|$ to $|Z_2|$ will give the ratio of the scattered energy to the energy obtained directly from the array and comes out to

$$20 \log_{10} \frac{|Z_M|}{|Z_2|} = 20 \log \frac{|1 + j10|}{|73|} = -17.2 \text{ db.}$$

Or, the power received (and re-radiated) by a shorted half-wave antenna can be calculated as follows

$$P_R = \frac{P_T \, G_T}{4\pi \, R^2} A_R$$

Where $P_T$ is power radiated by the first antenna whose gain is $G_T$,

$A_R$ is the effective aperture of the second antenna and

R is the spacing between them.

Feeding in the appropriate values, we find that

$$\frac{P_R}{P_T} \text{ is } -17.7 \text{ db.}$$

Looking back at Figure 2, we note that the resonant scatter measured experimentally is about -17.5 db.

Variation of Scatter With Distance of Building From the Array

A limited number of tests were made with 8 in (200 ft) building at different distances from the array along a line at right angles to the axis of the array. The range of distances covered was from 1 to 3 meters (1000 ft to 3000) - limited by the turntable size. Experimental values obtained were found to vary in a 1/R manner to within ± 1 db.

It, therefore, appears that the case of tall buildings can be treated theoretically as fat monopoles and their scatter signal calculated by taking into account the incident field strength from the AM array and assuming that the scattered signal is omni-directional.

## Re-Radiation from Transmission Lines

Transmission lines cover a greater distance than a single building; therefore, in order to accommodate more towers on the turntable, a scale factor of 600 was used. A new array was built for 600 MHz again producing a figure of eight pattern with nulls of the order of -40 db.

Scale transmission lines of 3 to 7 towers with tower spacing ranging from 1/2 to 1 wavelength (500 to 1000 ft) at distances of 2 to 5 wavelengths (2000 to 5000 ft) from the array have been used. Several orientations of the line relative to the broadcast array have been used. In all cases, the tests were carried out with and without a top wire attached to the towers. Tower heights were 3.3 inches (167 ft).

The large number of patterns obtained are somewhat difficult to analyze, however, two definite items are quite evident.

(1) Patterns obtained with a top wire are notably cleaner than without a top wire. See Figures 6 and 7 where patterns with and without a top wire are shown for the case of a transmission line parallel to the array axis at a distance of 5 wavelengths (5000 ft).

(2) For most orientations of the transmission line, the 1/2 wavelength (500 ft) spacing of towers produces less scatter than the other spacings tested. This is shown in Figures 8 and 9 where patterns for three towers are shown at 1/2 and 1 wavelength spacing, respectively.

More analysis will have to be carried out to get the maximum information from the transmission line patterns obtained.

## Conclusion

It has been shown that the Ship Range facility is more than adequate to detect and measure signals re-radiated by scale model buildings and transmission lines. Full scale distances up to a mile have been used.

Scatter from single buildings appears to be predictable by treating the building as a fat monopole and calculating the appropriate impedances.

Transmission lines contain many more variables and at the moment, the patterns obtained do not readily suggest a method for predicting the scatter.

W. Lavrench,
Electromagnetic Engineering Section,
11 October 1977.

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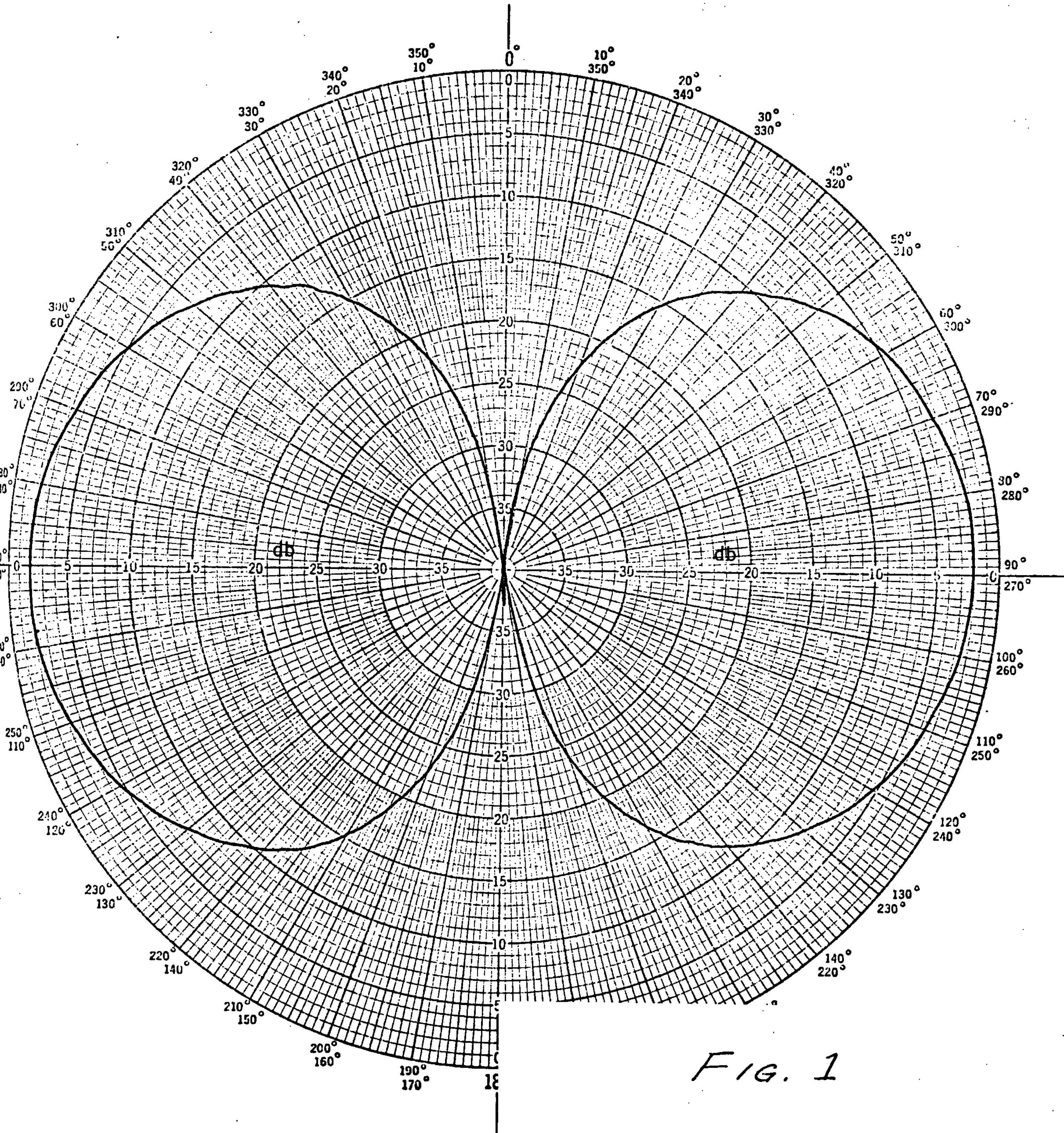
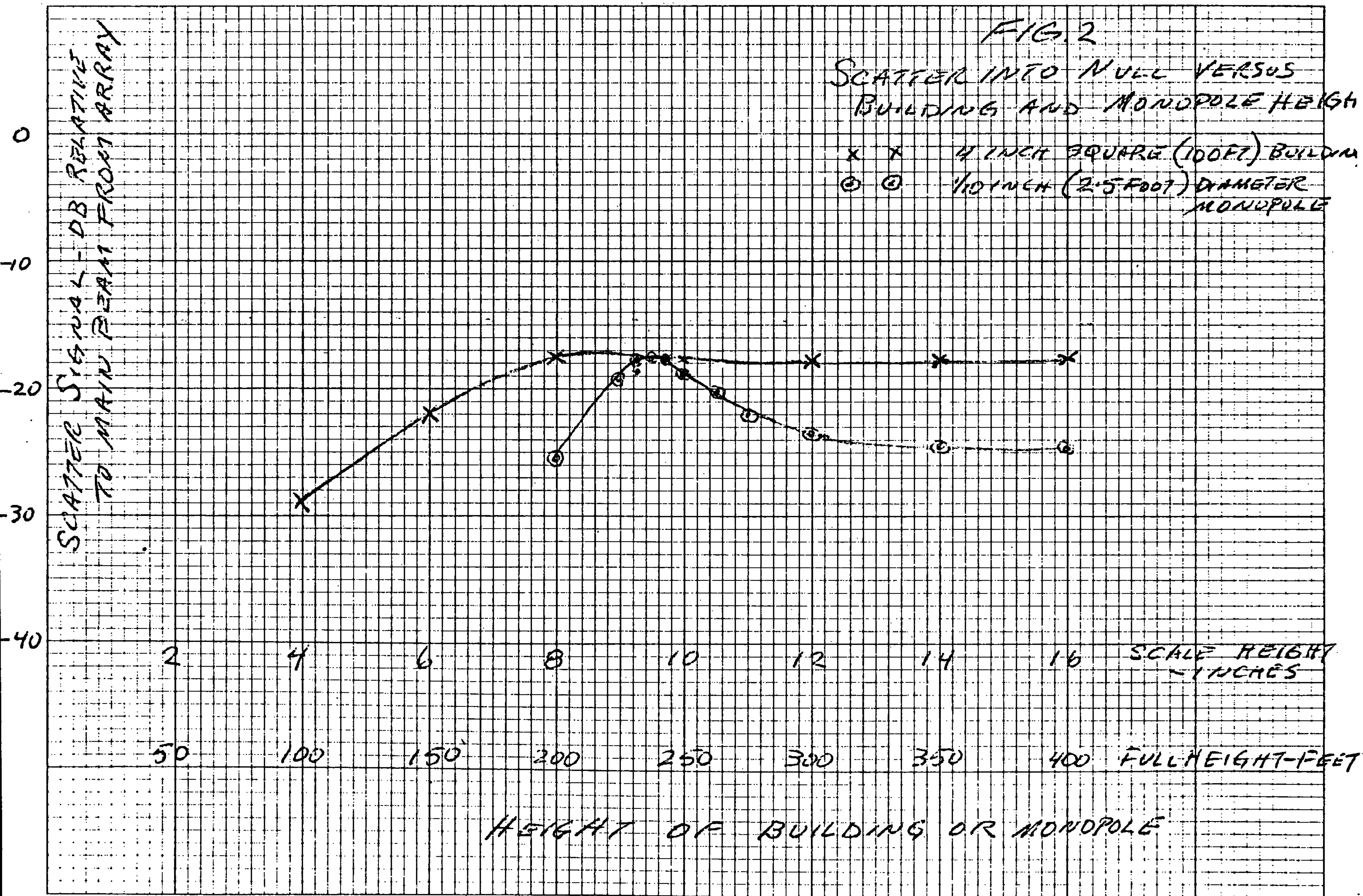



FIG. 1

PATTERN OF ARRAY USED IN TESTS

Polar Chart No. 127D
SCIENTIFIC-ATLANTA, INC.
ATLANTA, GEORGIA

FIG. 2


SCATTER INTO NULL VERSUS
BUILDING AND MONOPOLE HEIGHT
X X 4 INCH SQUARE (100FT) BUILDING
⊙ ⊙ 1/10 INCH (2.5 FOOT) DIAMETER MONOPOLE
SCATTER SIGNAL - DB RELATIVE TO MAIN BEAM FROM ARRAY
0
-10
-20
-30
-40
2
4
6
8
10
12
14
16
SCALE HEIGHT ~INCHES
50
100
150
200
250
300
350
400
FULL HEIGHT-FEET
HEIGHT OF BUILDING OR MONOPOLE

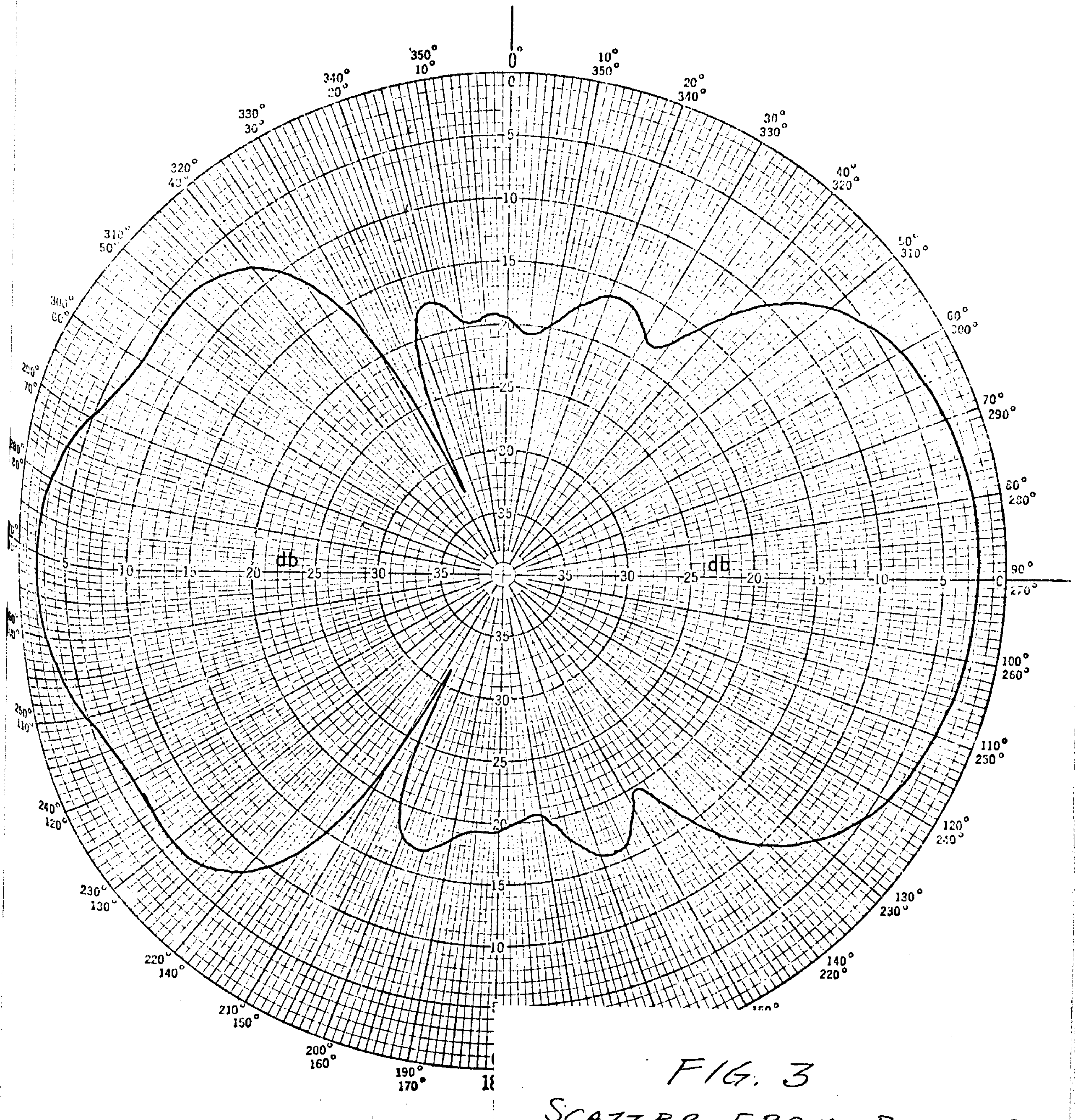



FIG. 3

SCATTER FROM BUILDING
HT. = 8 INCHES (200 FEET)
DIST. = 2 M (2000 FEET)

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SCIENTIFIC-ATLANTA, INC.
ATLANTA, GEORGIA

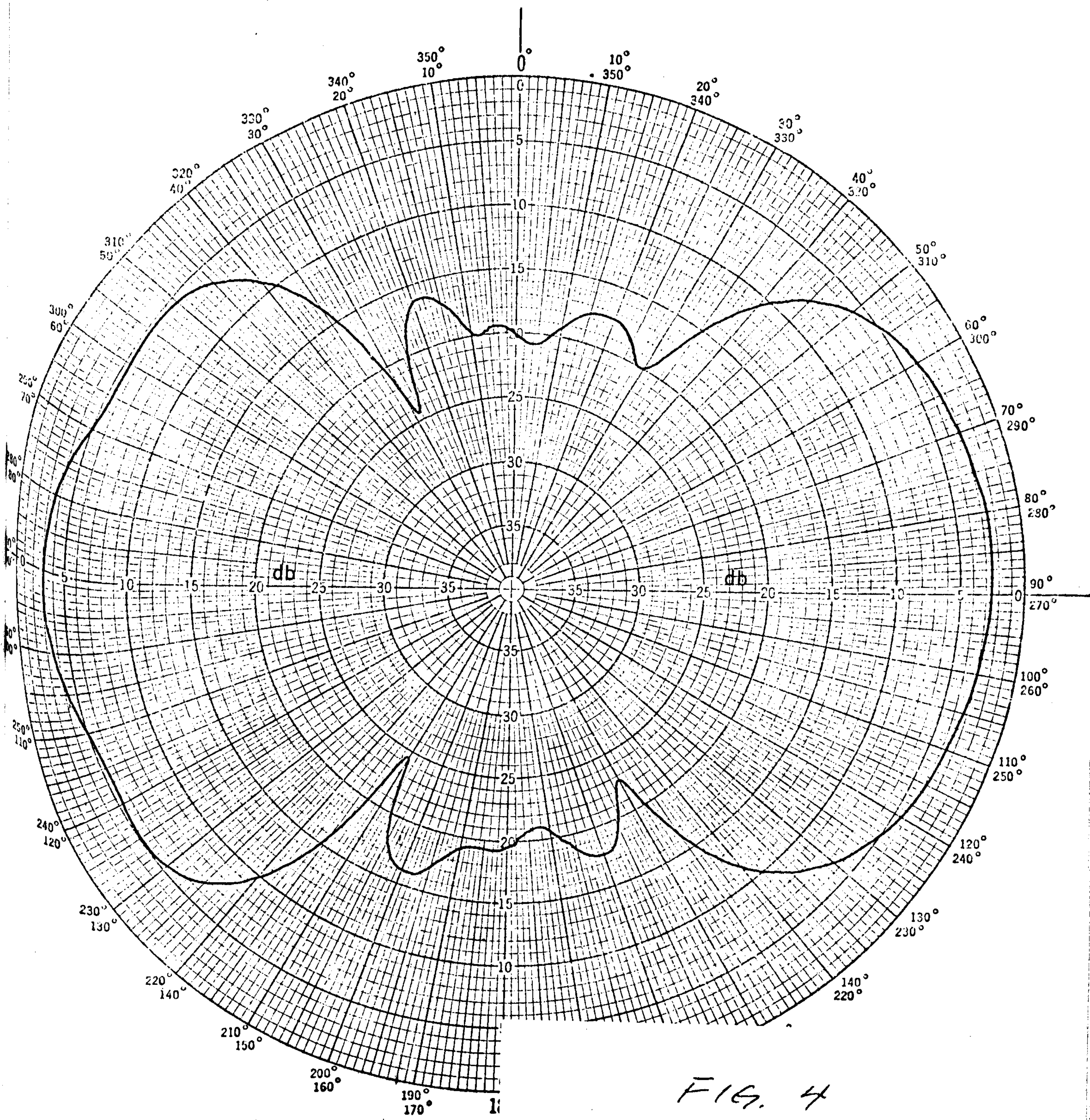


FIG. 4

SCATTER FROM BUILDING
HT. = 12 INCHES (300 FEET)
DIST. = 2 M (2000 FEET)

Polar Chart No. 127D
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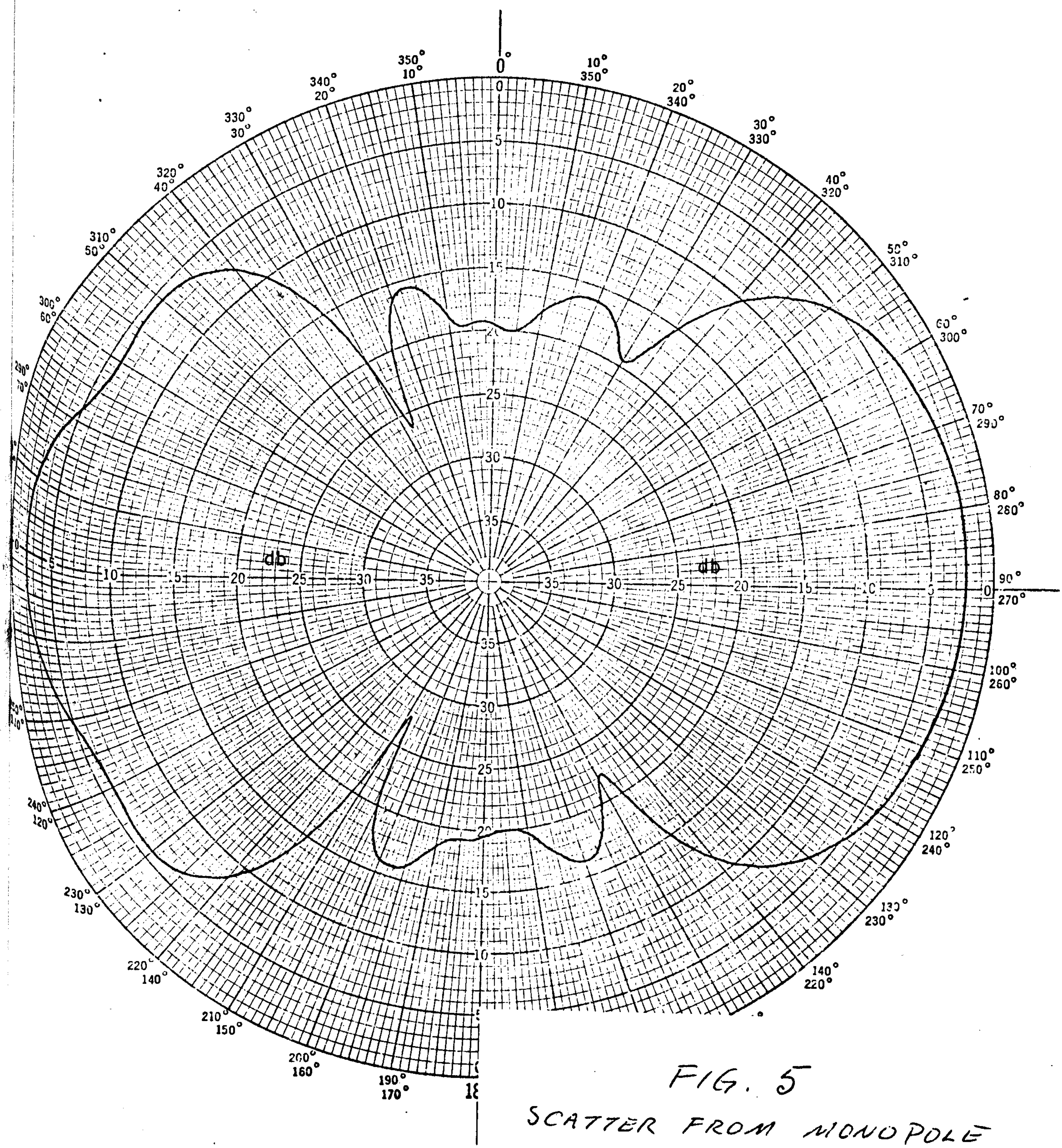


FIG. 5

SCATTER FROM MONOPOLE

HT. = 9 1/2 INCHES (237.5 FEET)

DIST. = 2 M (2000 FEET)

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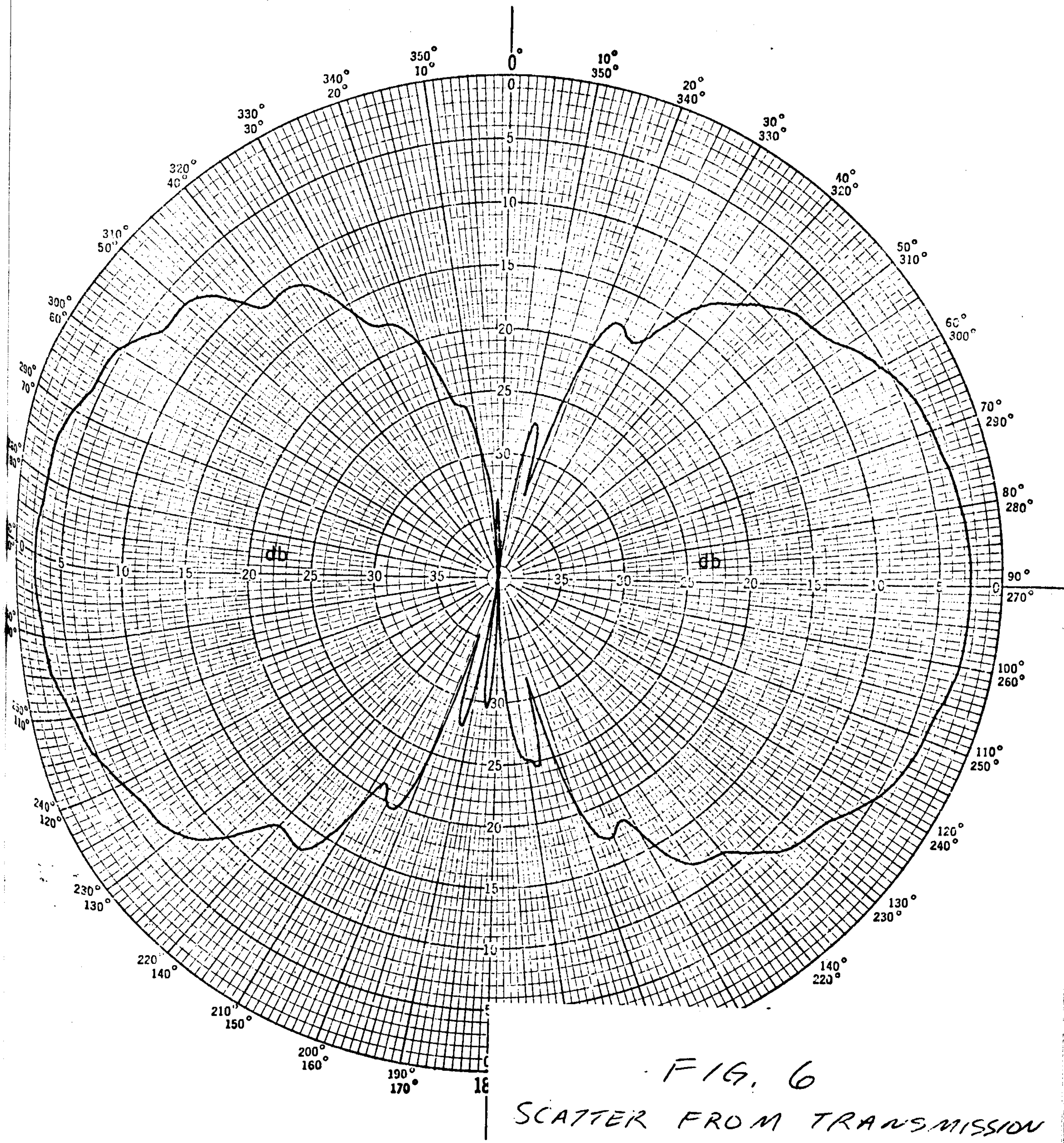


Polar Chart No. 127D
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FIG. 6

SCATTER FROM TRANSMISSION LINE

5 TOWERS : WITH TOP WIRE

SPACING = .5M (1000 FEET)

DIST. = 2.5M (5000 FEET)

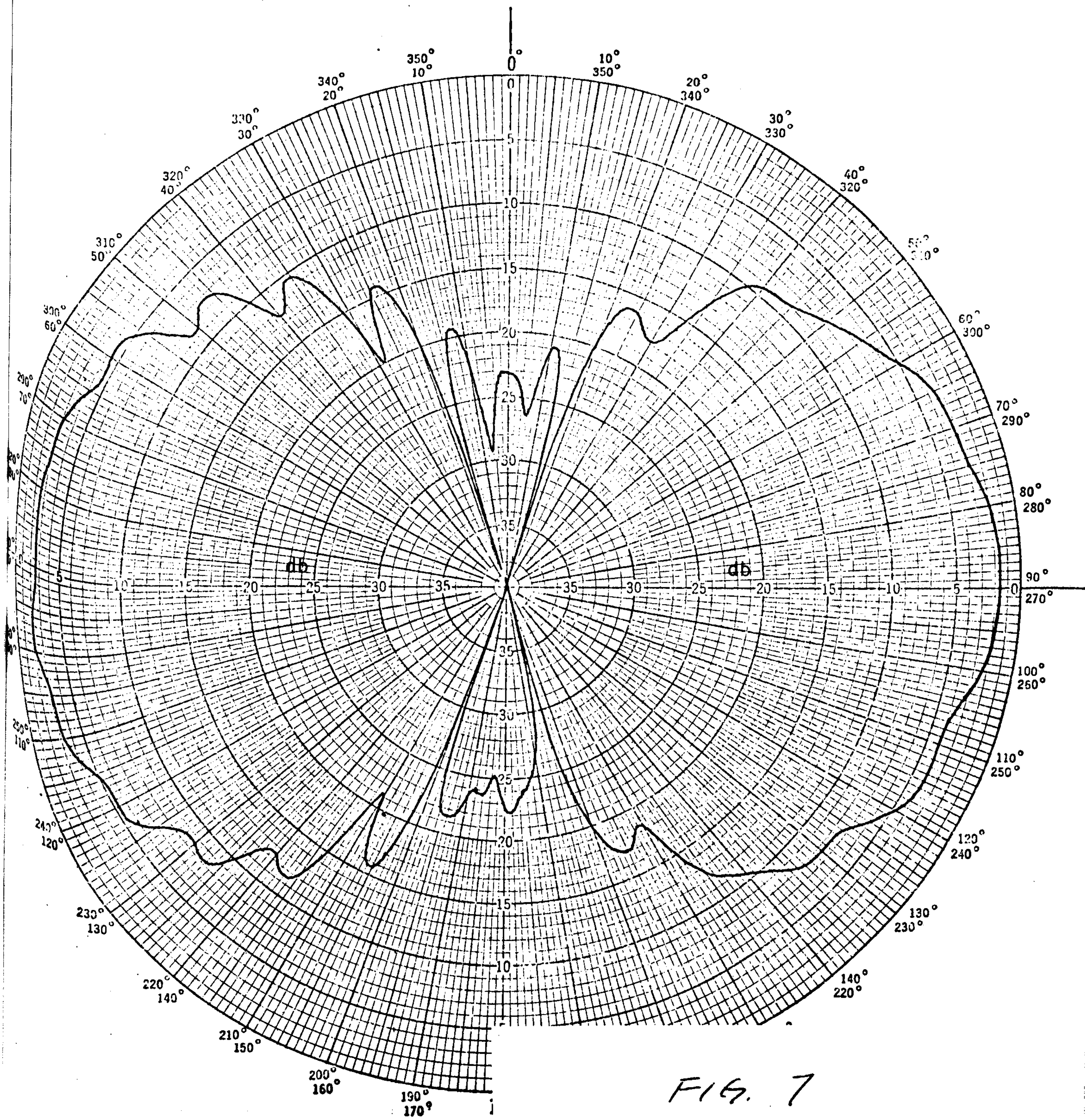

FIG. 7

SCATTER FROM TRANSMISSION LINE

5 TOWERS : NO TOP WIRE

SPACING = ·5 m (1000 FEET)

DISTANCE = 2.5 m (5000 FEET)

Polar Chart No. 127D
SCIENTIFIC-ATLANTA, INC.
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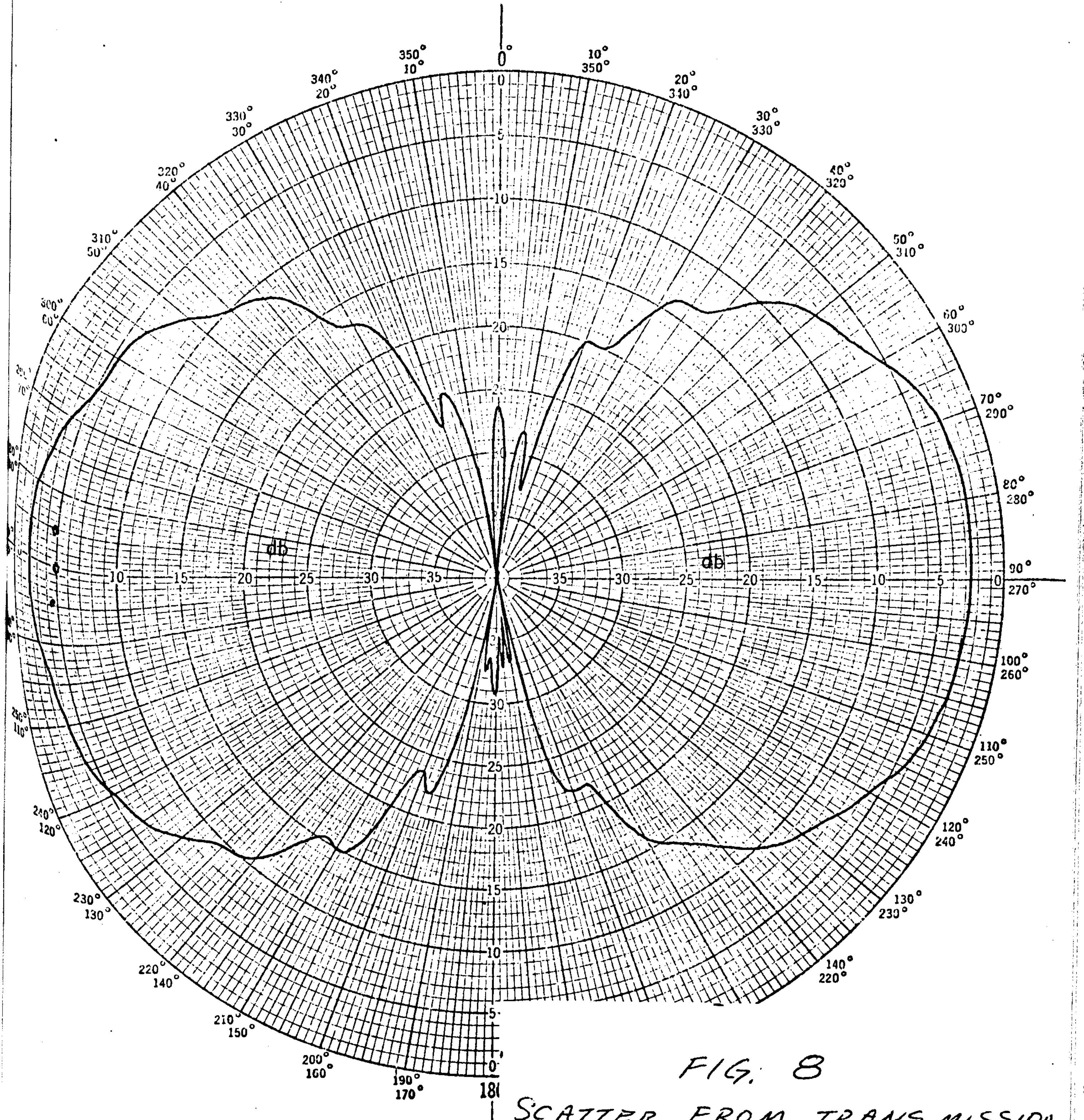


FIG. 8

SCATTER FROM TRANSMISSION LINE

3 TOWERS : NO TOP WIRE

SPACING = .25M (500 FEET)

DISTANCE = 2.5M (5000 FEET)

Polar Chart No. 127D
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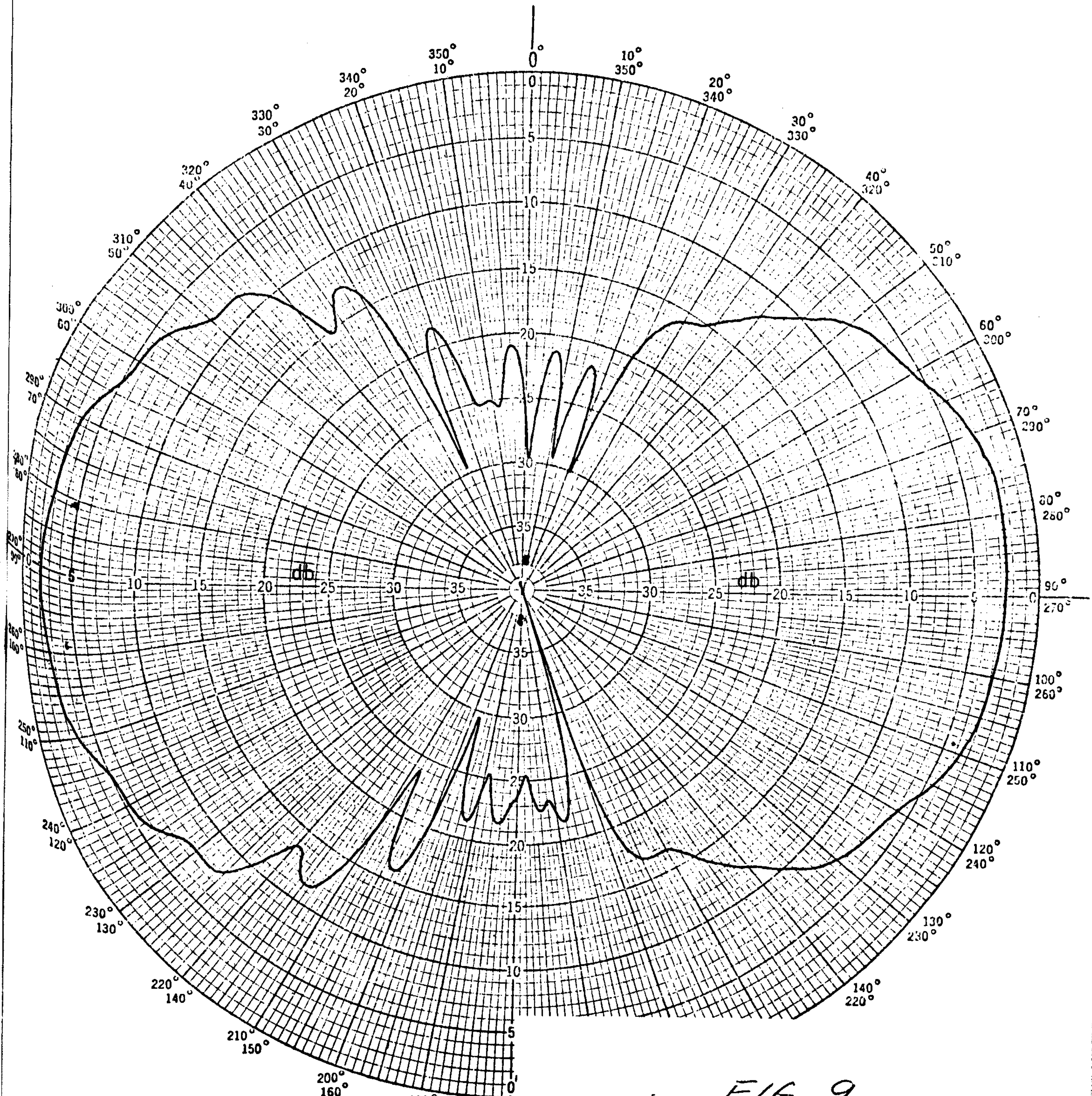



FIG. 9

SCATTER FROM TRANSMISSION LINE

3 TOWERS : NO TOP WIRE

SPACING = .5 M (1000 FEET)

DISTANCE = 2.5 M (5000 FEET)

Polar Chart No. 127D
SCIENTIFIC-ATLANTA, INC.
ATLANTA, GEORGIA

# Interim Report on University of Toronto Work

## STATUS

Work on the contract commenced on 1 September 1977, with the expectation that financial arrangements would be completed within about two months.

## PERSONNEL

K.G. Balmain, Professor, Principal Investigator

P.C. Kremer, Engineering Technologist IV

J.F. Laroye, Engineering Assistant

## PROGRESS

### General

The objective during this early period in the contract was to construct scale models of power lines and high-rise buildings and, to carry out preliminary experiments in order to measure the order of magnitude of the re-radiation phenomena and to identify useful measurement techniques.

Measurements were carried out in an anechoic chamber with an open volume measuring approximately 4m x 5m, and 3.5m high. The antenna arrangement within the chamber is shown in Figure 1. The distance from the range antenna to the phase centre of the model antenna plus re-radiator is approximately 4m, a distance equal to $D^2/\lambda$ at 500 MHz and equal to $2D^2/\lambda$ at 1000 MHz for a maximum re-radiator width D of 1m. Thus, it can be seen that the far-field criterion is marginally satisfied.

For model construction, the nominal scale chosen is 1000:1, so that experimental MHz translates into kHz and millimeters into meters. Thus, with the present set-up, re-radiators up to 1km in horizontal dimensions can be studied.

The experimental arrangements are illustrated in Figure 1. A vertically polarized log-periodic "model antenna" is used to illuminate a model power line or model building mounted on an insulated turn-table and the received field intensity comprising direct and forward scattered fields are measured by the "range antenna". The turn-table is held at a fixed angle $\alpha$ as the frequency is swept or rotated for a fixed frequency through $\alpha$ values ranging from $0^o$ through $90^o$.

The tests are conducted in free space without a ground plane, so that the model includes the image of the re-radiator. Thus, the model represents a perfectly conducting ground at full scale.

## Re-Radiation by Power Lines

The model power lines are depicted in Figure 2 which indicates that most of the resonant frequencies should lie in the available frequency range of 450 to 1050 MHz. Model tower heights of 99mm correspond to actual tower heights of 324 feet; i.e., grounded tower heights of 162 feet. The five-tower re-radiator (when spaced at d = 50cm (1640 feet) from the model antenna) represents approximately the power line passing close to the CBC Toronto antenna at Hornby.

Figures 3 to 10 are swept-frequency and polar plots of total transmitted signal magnitude for the five-tower model with a grounded sky-wire. The long axis of the graphs is frequency or angle $\alpha$ and the short axis of the graphs field intensity on a scale of 2 db/cm. Clearly, the re-radiation effects are strong under resonant conditions toward either end of the frequency interval and weak under non-resonant conditions. The scaled frequency of station CJBC is 860 MHz which is close to the high frequency resonance region.

Figures 11 and 12 for 9-towers (half the tower spacing or 450 feet at full scale) display more clearly the low frequency resonance effects.

Figures 13 and 14 show typical results of an insulated sky-wire (insulated from the model tower by means of a thin layer of Teflon tape). More resonances are noticeable and all but one are relatively weak. However, because this one resonance is very strong, it would seem risky to generalize about the relative value of insulated sky-wires.

## Initial Interpretation of Results

The dashed curve which is plotted in Figures 3, 7, 11, 13 (as well as in 16, 17 and 18 which are results for buildings) is the received field intensity in the absence of re-radiators. The various curves represent the received field intensity with re-radiators (power lines or buildings) and the difference in db between the two curves can be readily scaled from the graphs. The relationship between the null field of a broadcast array and the scatter or interference field (difference between the actual field and the field for the case where there are no re-radiators) can be estimated approximately from Table 1.

TABLE 1

| Null Field (db below maximum field) db | Scatter or Interference Field db |
|---|---|
| -1 | -19.3 |
| -2 | -13.7 |
| -3 | -10.7 |
| -6 | - 6.0 |
| -10 | - 3.3 |
| -20 | - 0.9 |
| -30 | - 0.3 |
| -40 | - 0.1 |

Thus, in Figure 3, the sharp peak resonance in the re-radiated field for $\alpha = 0$ at about 470 MHz, represents a deviation from the dashed curve (no re-radiators present) by about 8.5 db. Thus, the peak scatter or interference field is 8.5 db and, according to Table 1, the null field would be only -4.5 db below the maximum field. This is, indeed, a situation of very strong scatter.

Under non-resonant conditions five-towers with no wires produced pattern deviations of the order of 0.5 db while both grounded and insulated sky-wires produced deviations of about 0.7 db (i.e., the null fields would be -20 to -30 db below the maximum field).

## Re-Radiation by Buildings

Figure 15 shows the model for a pair of high-rise buildings. The cross-sectional dimensions of 1 x ½ inch and height of 3.5 inches (a building on a ground plane is half the height of a building without a ground plane) corresponds to actual dimensions of about 84 x 42 feet and 290 feet high. Figure 16 indicates a 2 db (maximum) pattern deviation for a spacing of 50cm from the model antenna and for a zero spacing between the broad faces of the buildings. Increasing this spacing produces the resonant effects visible in Figures 17 and 18. The maximum pattern deviation near resonance appears to be about 6 db, independent of building separation, for separations from 7.5 to 75mm. This indicates that groups of buildings may exhibit strong, peculiar re-radiation effects even if they are widely separated.

## CONCLUSIONS

The scatter field can be measured in the sweep frequency experiment as a deviation from the field in the absence of re-radiators. Resonant effects can be seen in the data and under such conditions, the scatter fields are strong. The pattern distortion of a directional array would under such a situation be badly distorted. Null fields ranging from -5 db to -30 db are indicated by these results. Future work will be directed towards improving the log-periodic antennae so that the field versus frequency will be more linear and in examining differing situations, particularly buildings and building complexes with greater spacings from the illuminating antenna array.

K.G. Balmain
Department of Electrical
Engineering
University of Toronto
Toronto, Ontario M5S 1A4

(With editorial additions
by J.S. Belrose, DOC/DRC)

20 October 1977

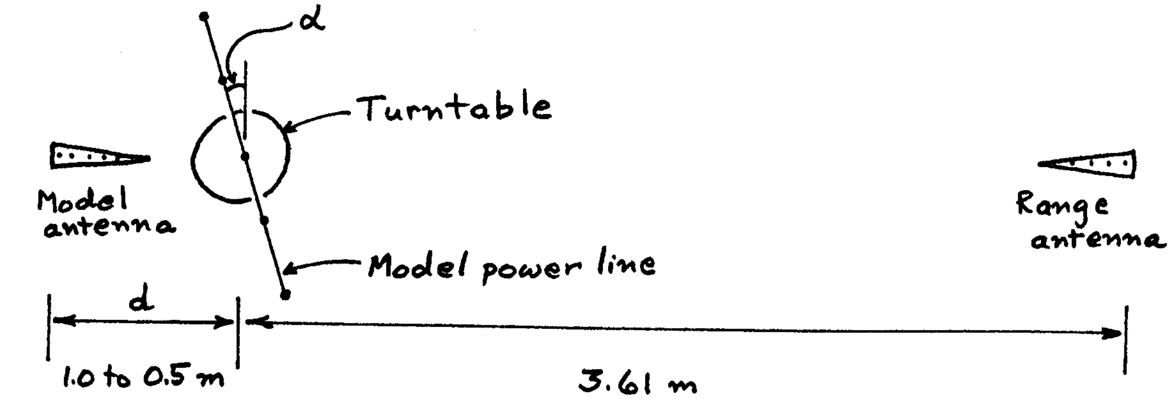
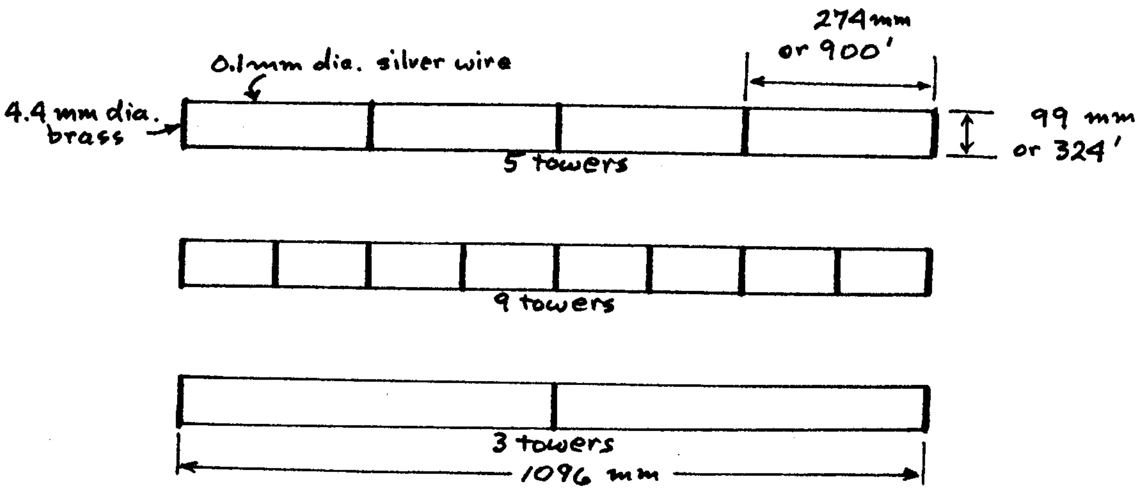



Fig. 1




| | Cell perimeter p | Resonant freqs. $f_n$ for $p = n\lambda$ |
|---|---|---|
| 5 Towers | 746 mm | 402 , 804 MHz |
| 9 Towers | 472 | 636 |
| 3 Towers | 1294 | 232 , 464 , 696 , 927 |

Fig. 2

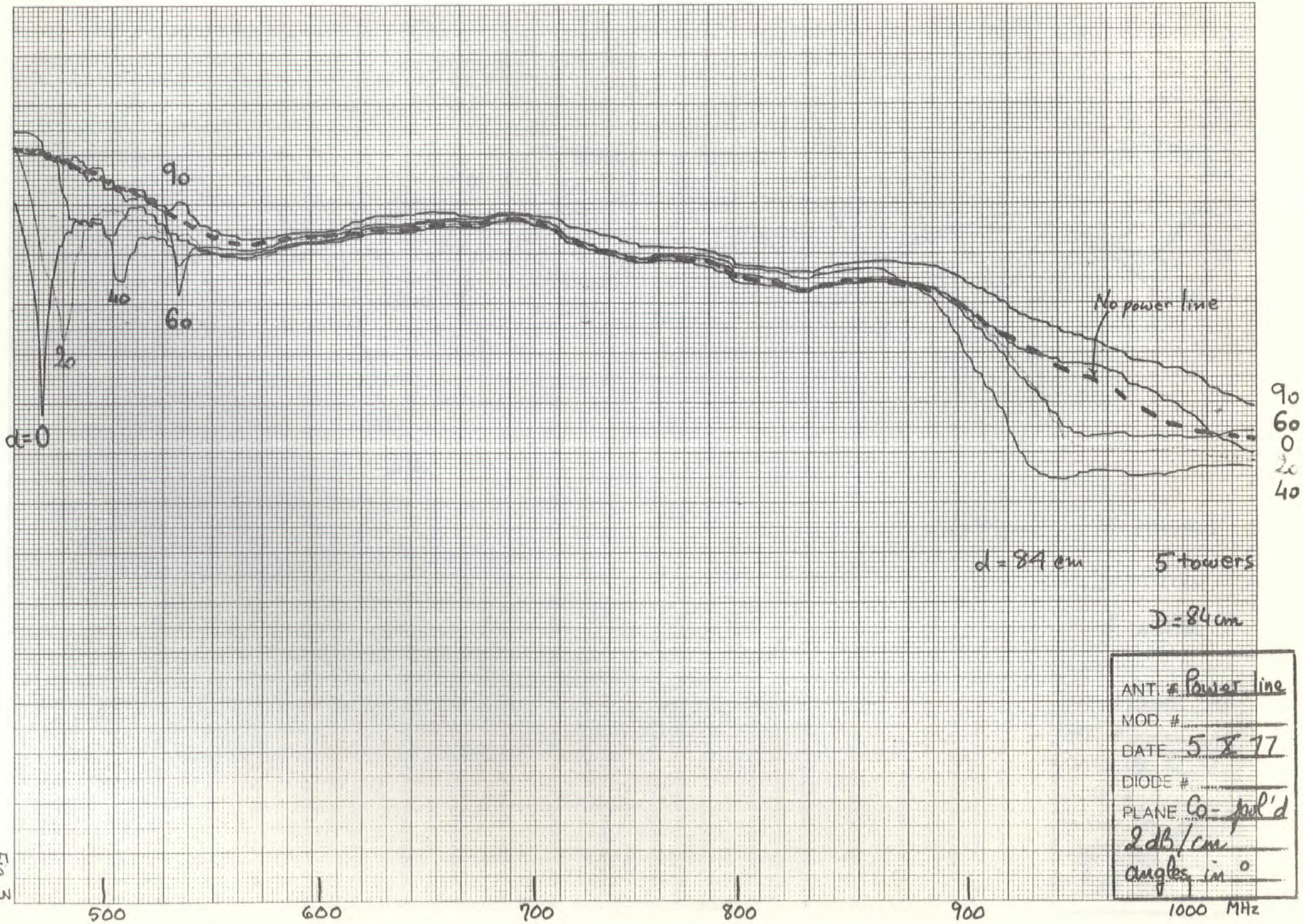

90
40
60
20
d=0
No power line
90
60
0
20
40
d = 84 cm
5 towers
D = 84 cm
ANT. # Power line
MOD. #
DATE 5 X 77
DIODE #
PLANE Co-pol'd
2dB/cm
angles in °
500
600
700
800
900
1000 MHz

Fig. 3

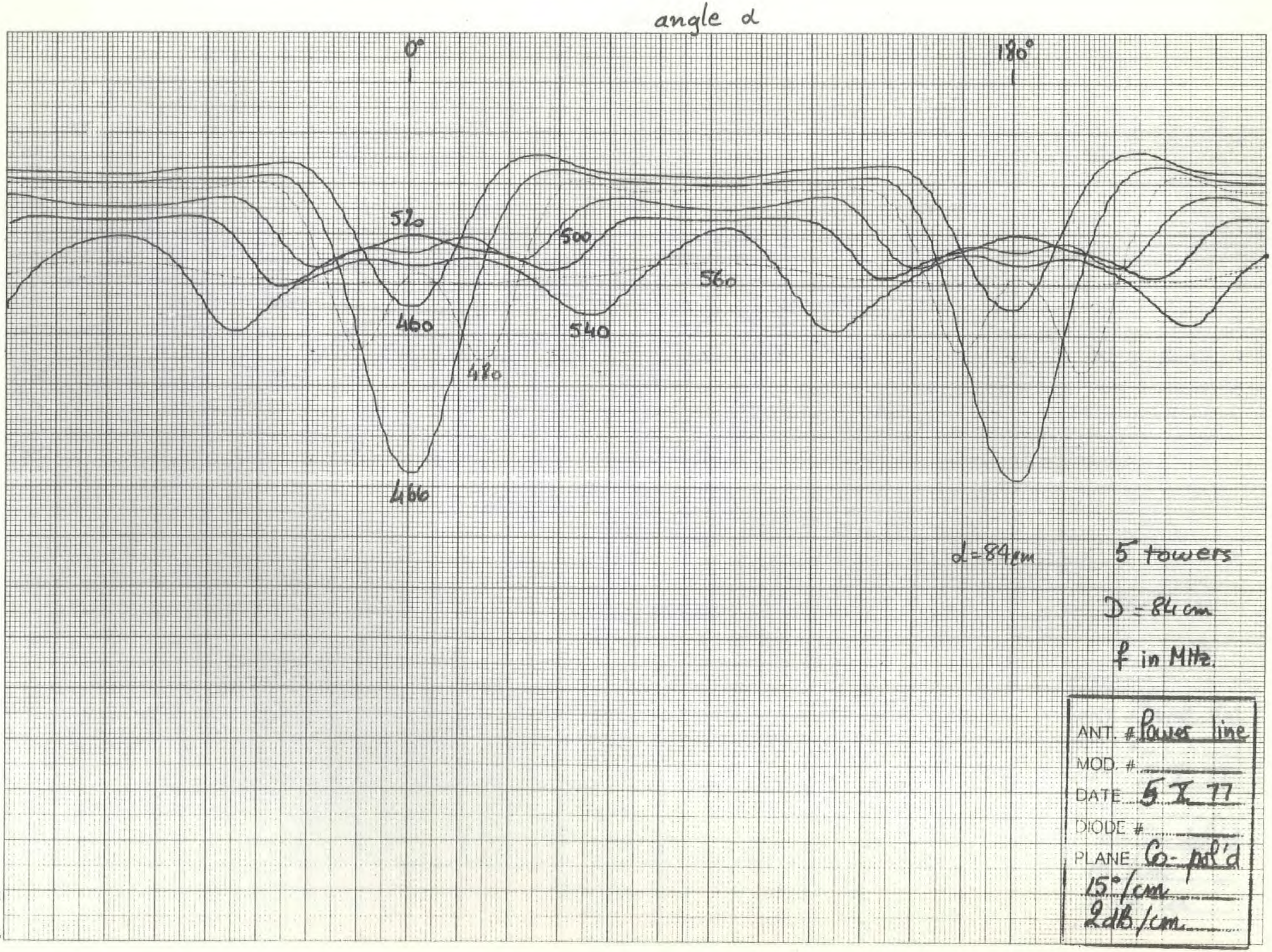

angle α
0°
180°
520
500
560
460
540
480
460
α=84cm
5 towers
D=84cm
f in MHz.
ANT. # Power line
MOD. #
DATE 5 X 77
DIODE #
PLANE Co-pol'd
15°/cm
2dB/cm

Fig. 4

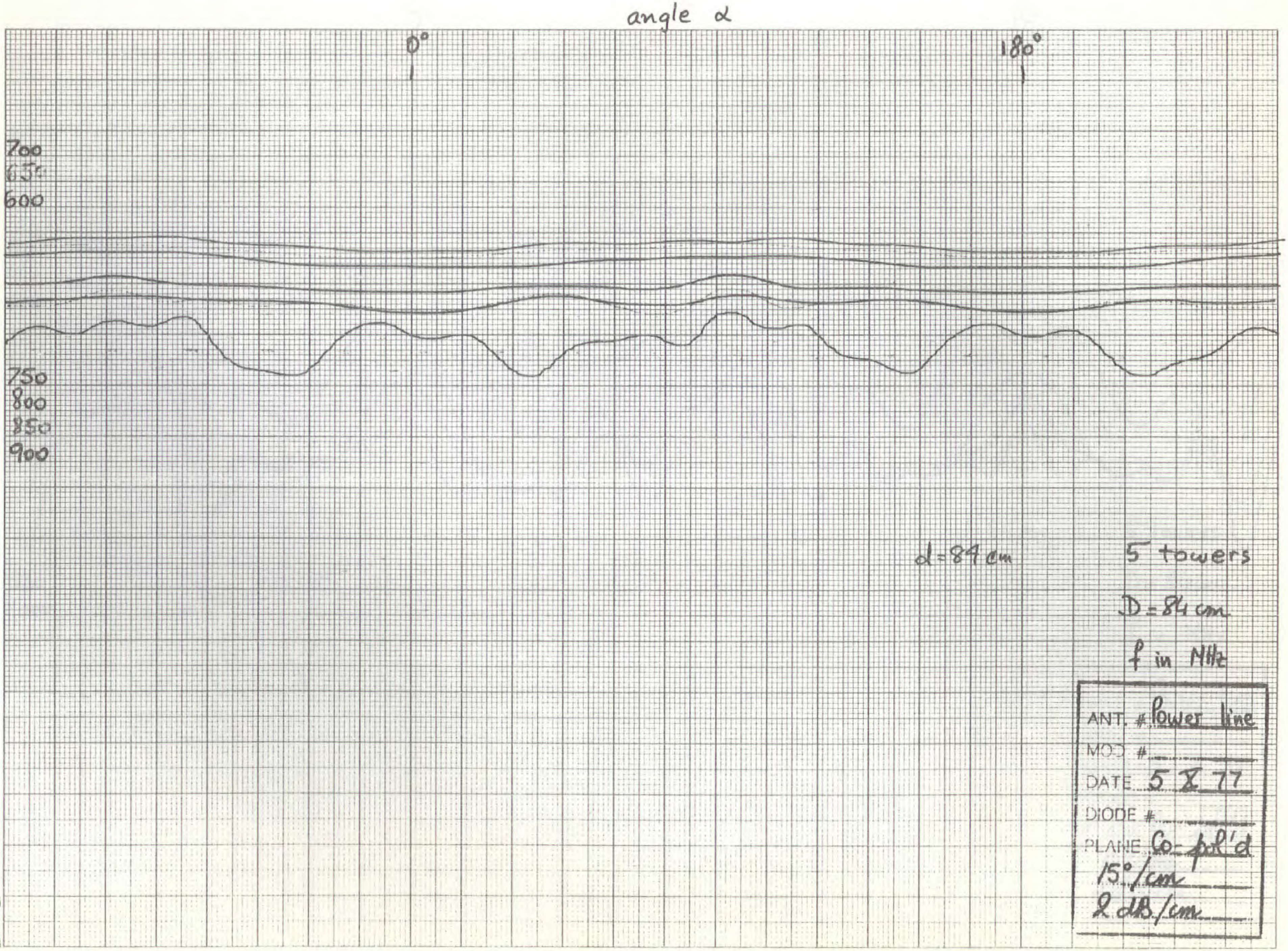

angle α
0°
180°
700
650
600
750
800
850
900
d=84 cm
5 towers
D=84 cm
f in MHz
ANT. # Power line
MOD #
DATE 5 X 77
DIODE #
PLANE Co-pol'd
15°/cm
2 dB/cm

Fig. 5

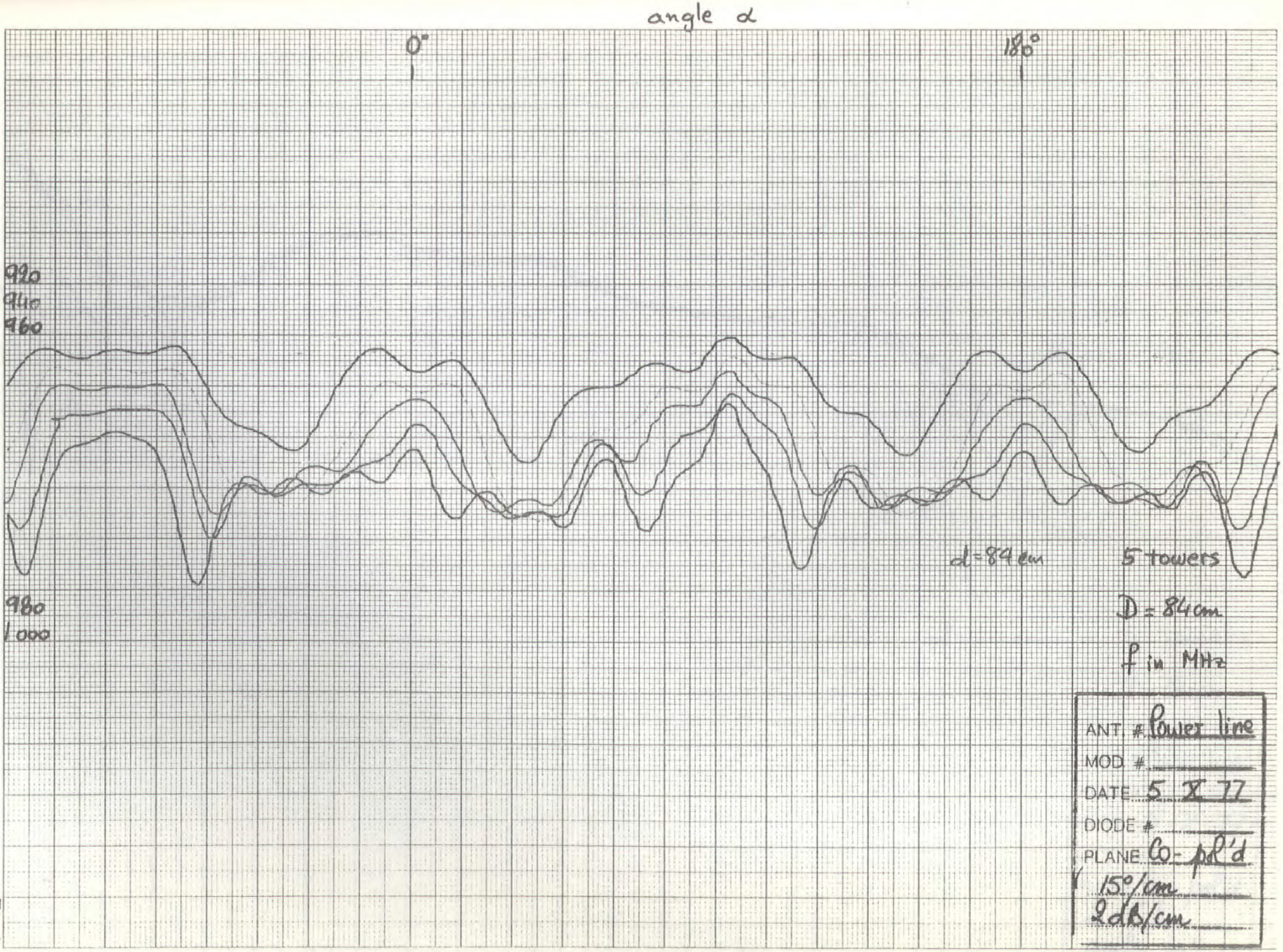

angle α
0°
180°
920
940
960
980
1000
d=84 cm
5 towers
D=84cm
f in MHz
ANT # Power line
MOD #
DATE 5 X 77
DIODE #
PLANE Co-pl'd
15°/cm
2dB/cm

Fig. 6

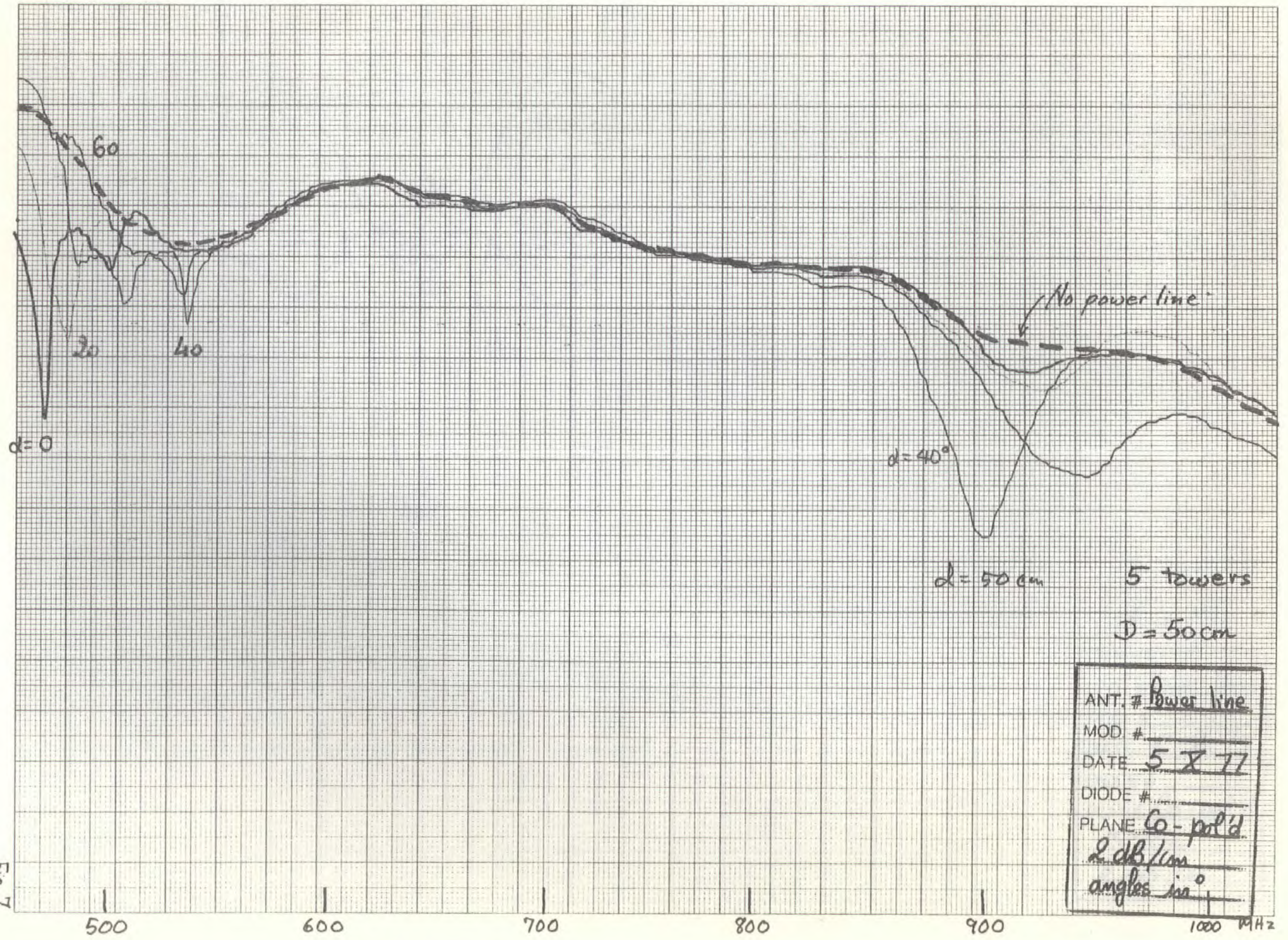
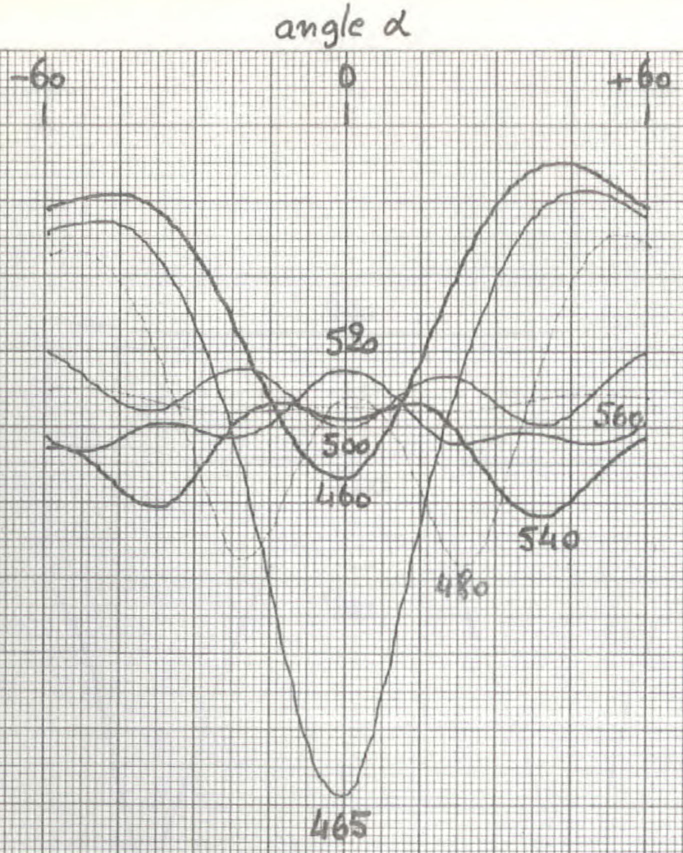

60
20
40
d= 0
No power line
d=40°
d= 50 cm
5 towers
D = 50 cm
ANT. # Power line
MOD #
DATE 5 X 77
DIODE #
PLANE Co-pol'd
2 dB/cm
angles in °
500
600
700
800
900
1000 MHz

Fig. 7




α = 50 cm

5 towers

f in MHz.

ANT. # Power line
MOD. # 
DATE 5 X 77
DIODE # 
PLANE Co-pol'd
15°/cm
2 dB/cm

Fig. 8

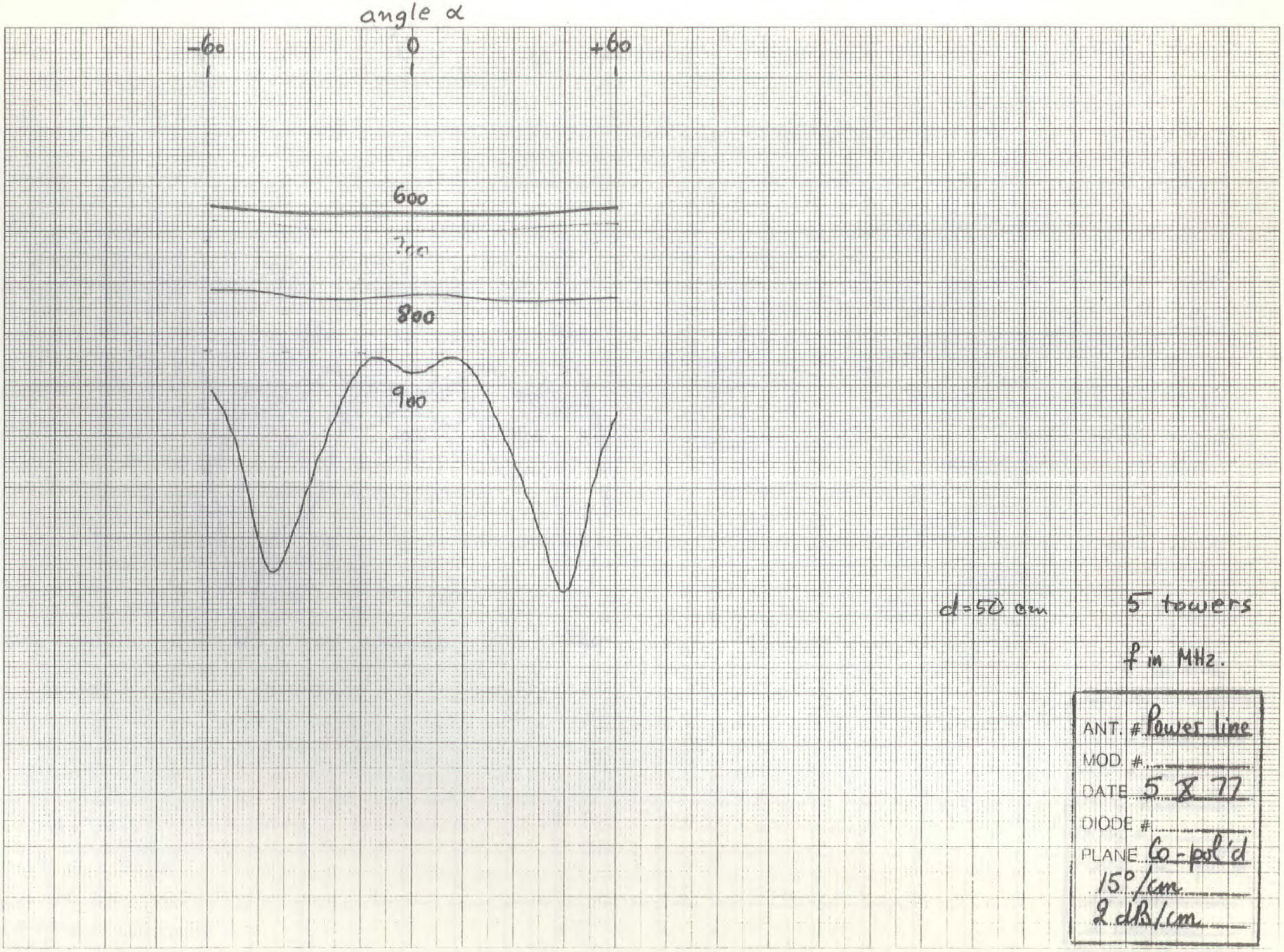

angle α
-60
0
+60
600
700
800
900
d=50 cm
5 towers
f in MHz.
ANT. # Power line
MOD. #
DATE 5 X 77
DIODE #
PLANE Co-pol'd
15°/cm
2 dB/cm

Fig. 9

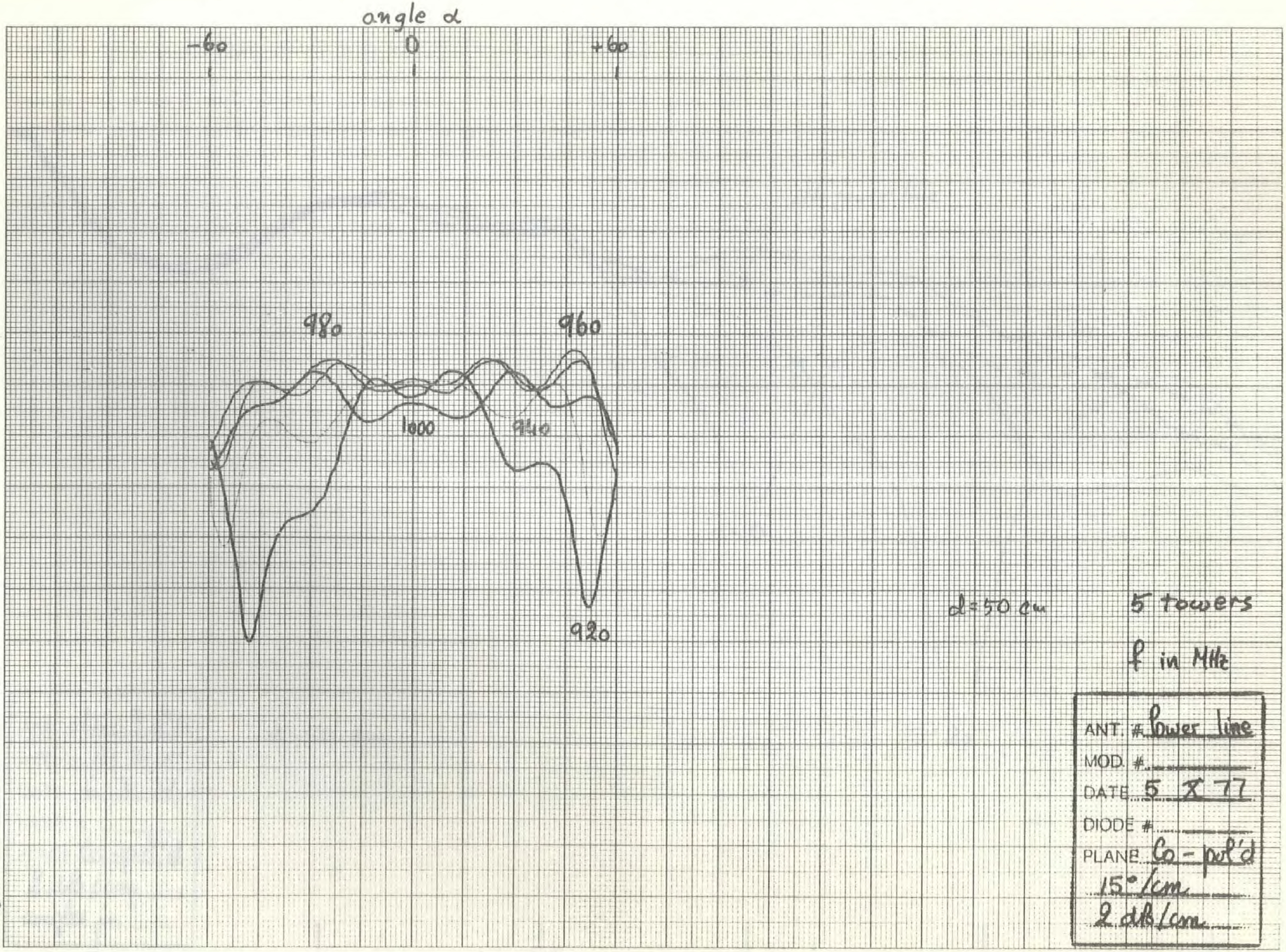

angle α
-60
0
+60
980
960
1000
940
920
d=50 cm
5 towers
f in MHz
ANT. # Power line
MOD. #
DATE 5 X 77
DIODE #
PLANE Co-pol'd
15°/cm
2 dB/cm

Fig. 10

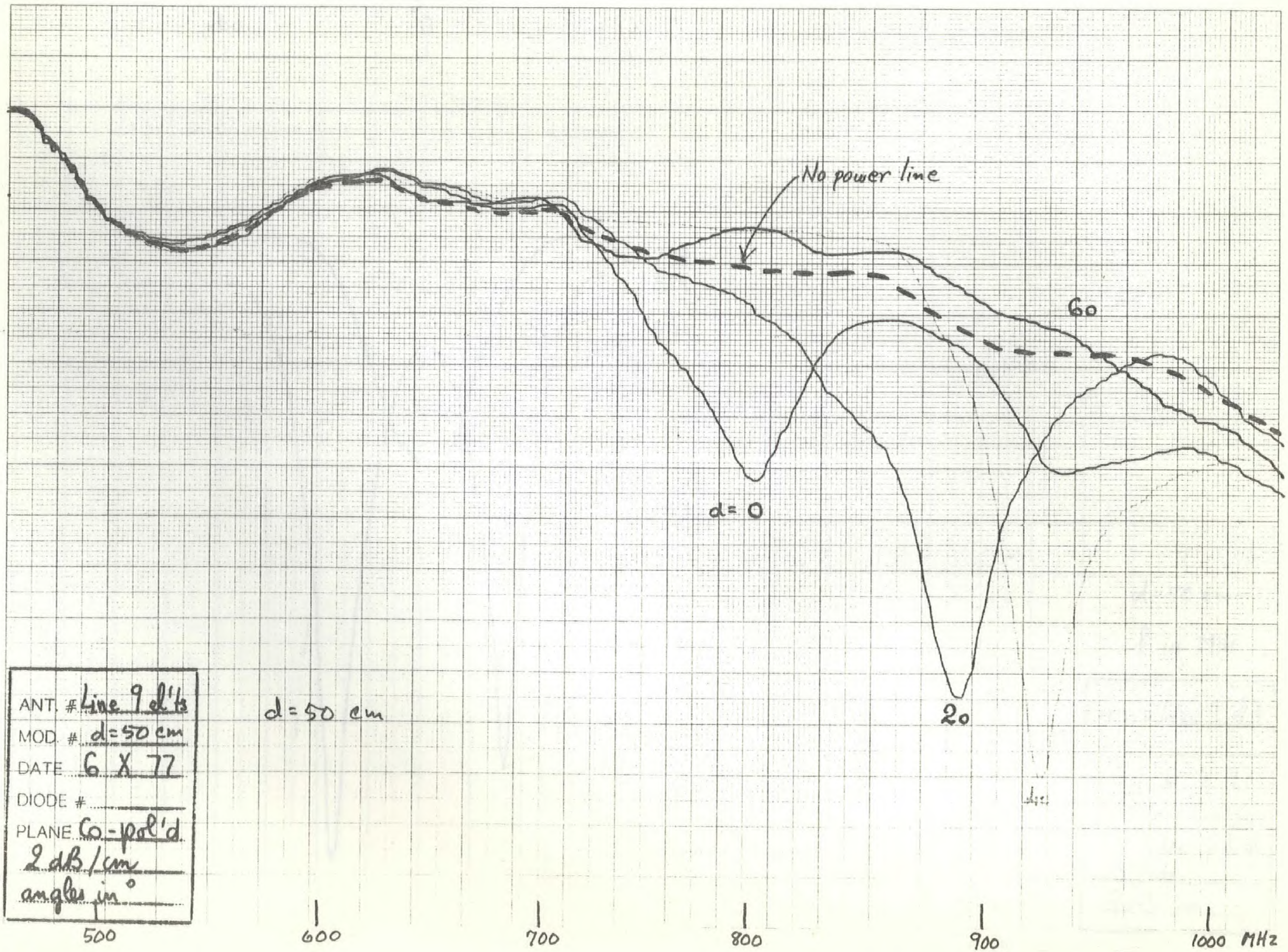
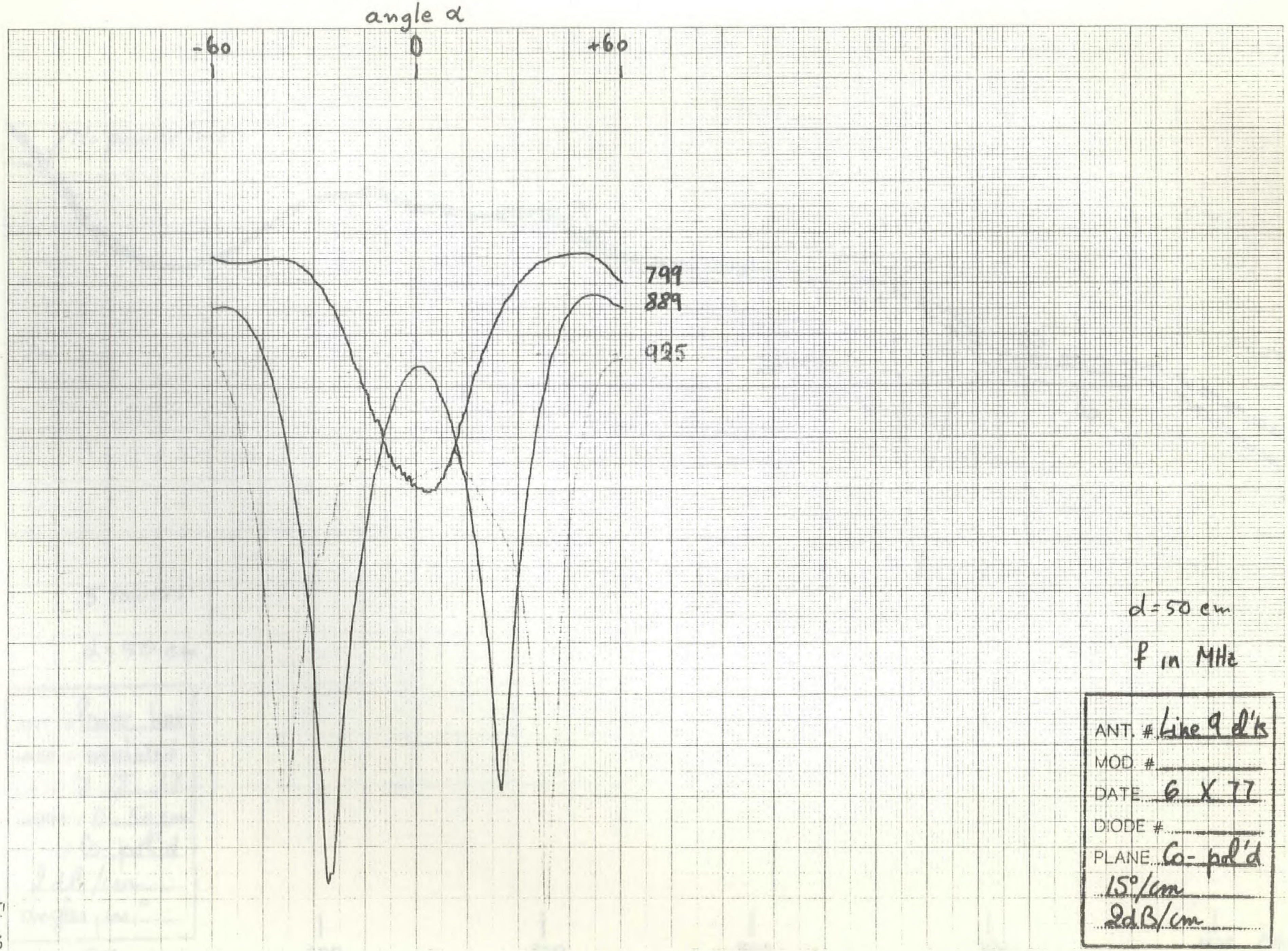

No power line
60
d= 0
20
d=50 cm
ANT. # Line 9 d'ts
MOD. # d=50 cm
DATE 6 X 77
DIODE #
PLANE Co-pol'd
2 dB/cm
angles in °
500
600
700
800
900
1000 MHz

Fig. 11



angle α
-60
0
+60
799
889
925
d=50 cm
f in MHz
ANT. # Line 9 d'ts
MOD. #
DATE 6 X 77
DIODE #
PLANE Co-pol'd
15°/cm
2dB/cm


Fig. 12

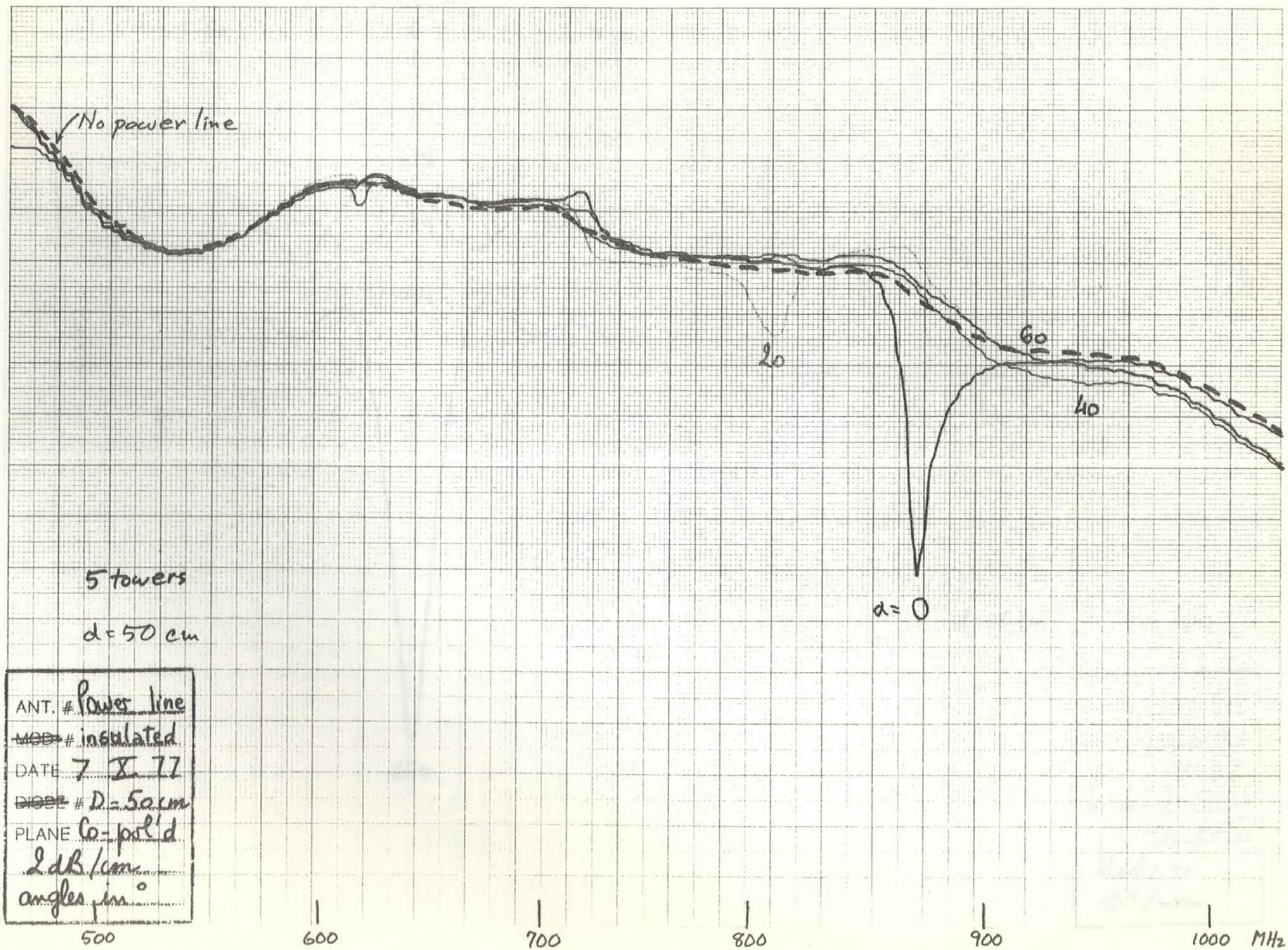
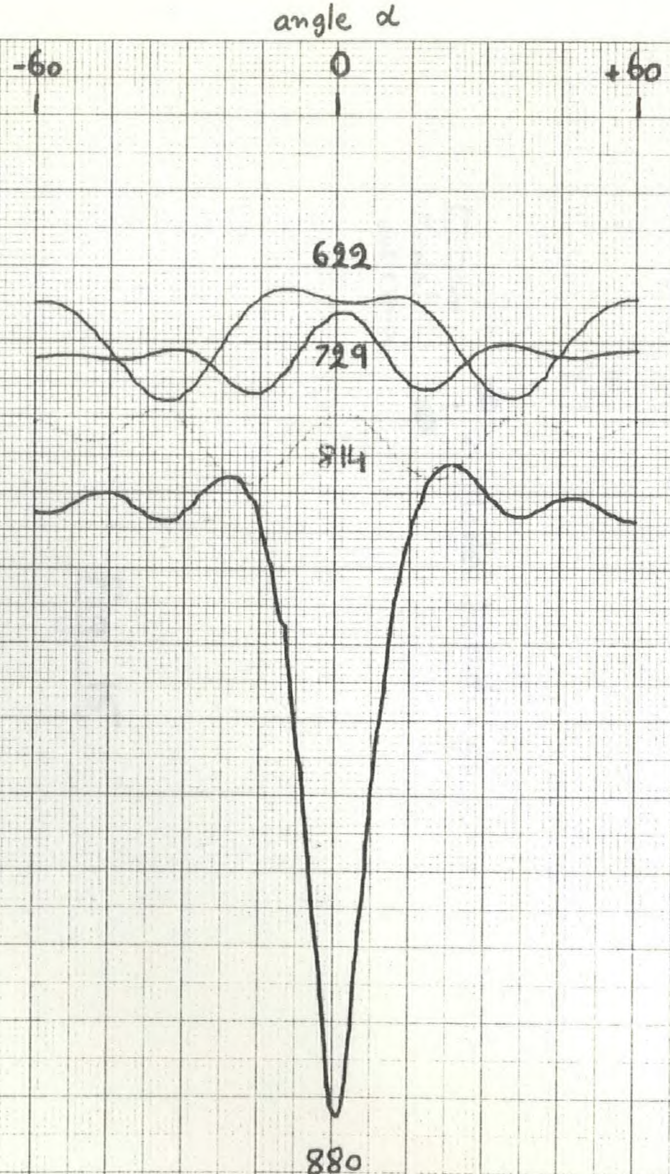

No power line
20
60
40
d = 0
5 towers
d = 50 cm
ANT. # Power line
# insulated
DATE 7 X 77
# D = 50 cm
PLANE Co-pol'd
2dB/cm
angles in °
500
600
700
800
900
1000
MHz

Fig. 13




d=50cm f in MHz

ANT. # Power line
~~MOD~~ # insolated
DATE 7 X 77
~~DIODE~~ # D=50cm
PLANE Co-pol'd
2dB/cm
15°/cm

Fig. 14

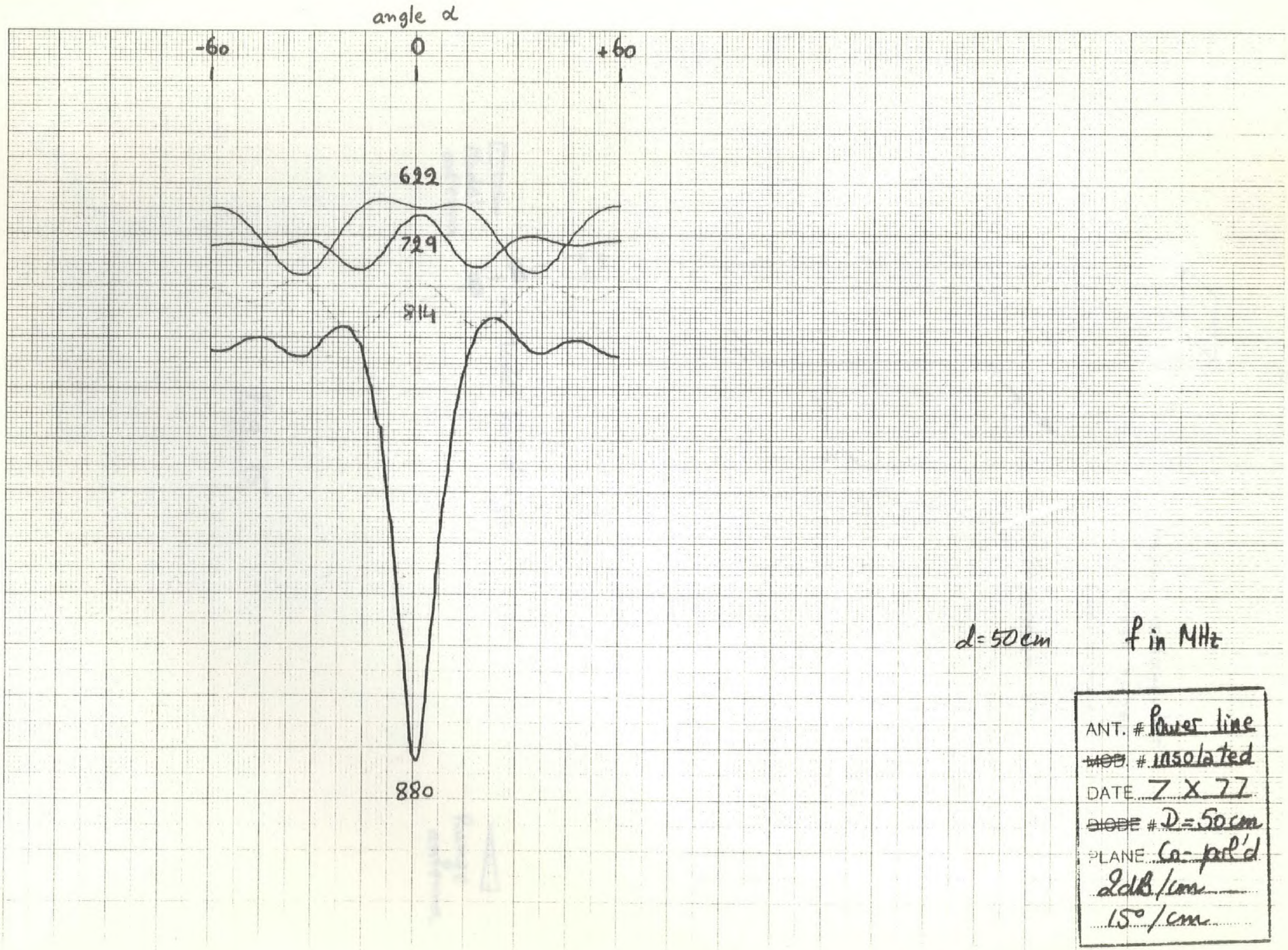

angle α
-60
0
+60
622
729
814
880
d=50cm
f in MHz
ANT. # Power line
MOD. # insolated
DATE 7 X 77
DIODE # D=50cm
PLANE Co-pol'd
2dB/cm
15°/cm

Fig. 14

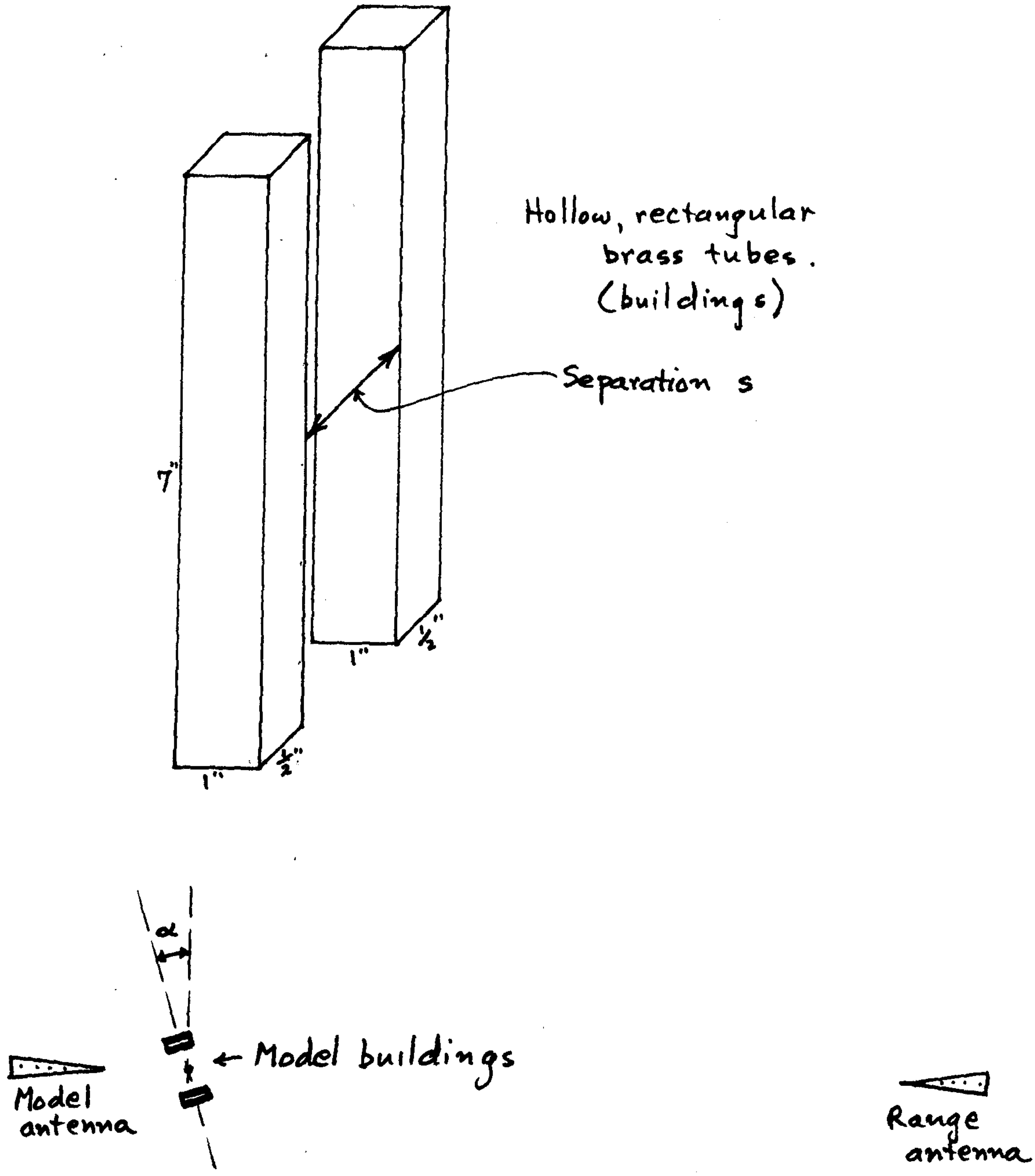
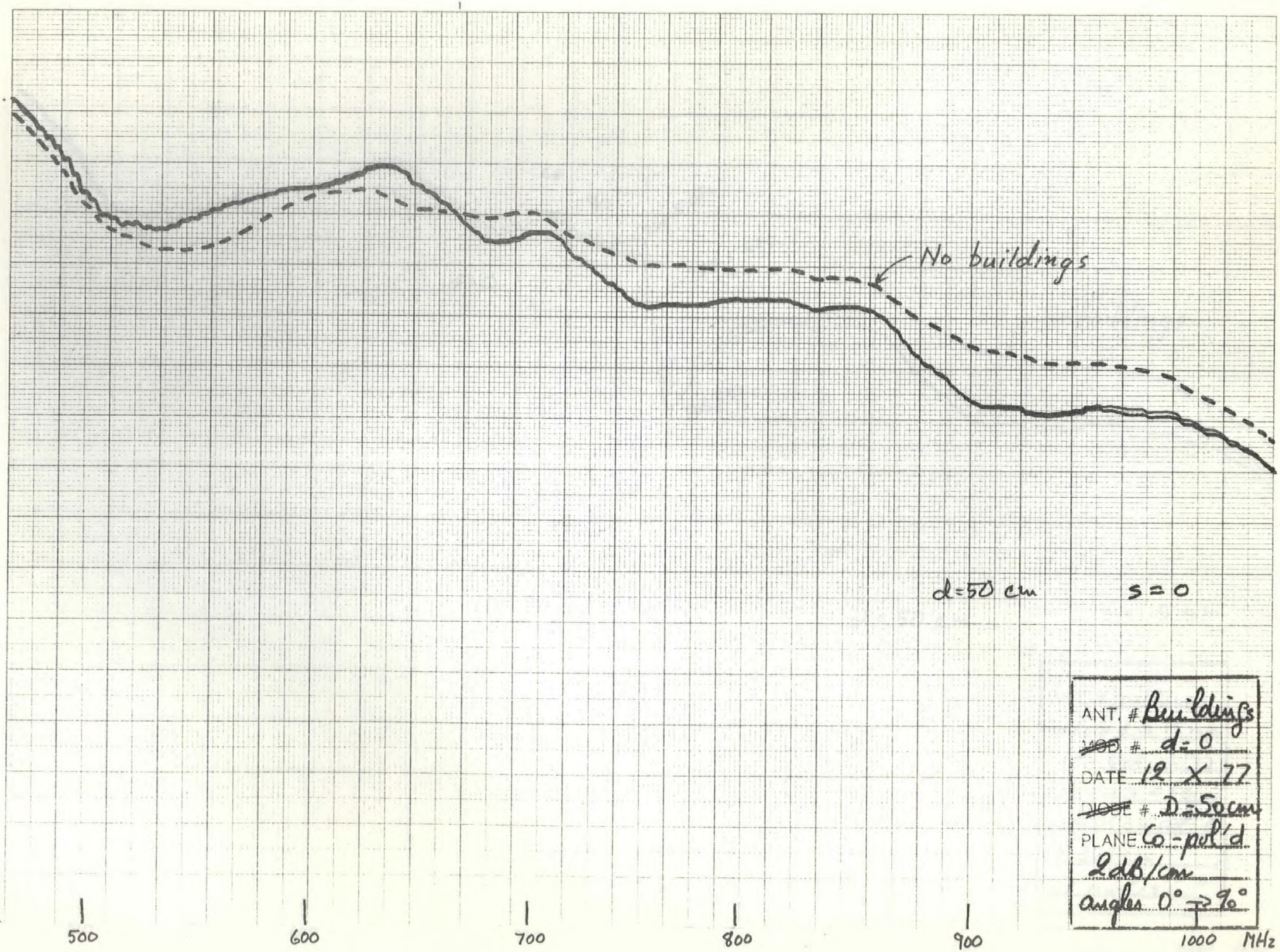

Hollow, rectangular brass tubes. (buildings)
Separation s
7"
1"
½"
1"
½"
α
← Model buildings
Model antenna
Range antenna

Fig. 15



No buildings
d=50 cm
s = 0
ANT. # Buildings
MOD. # d=0
DATE 12 X 77
DIODE # D=50cm
PLANE Co-pol'd
2dB/cm
angles 0° → 90°
500
600
700
800
900
1000
MHz


Fig. 16

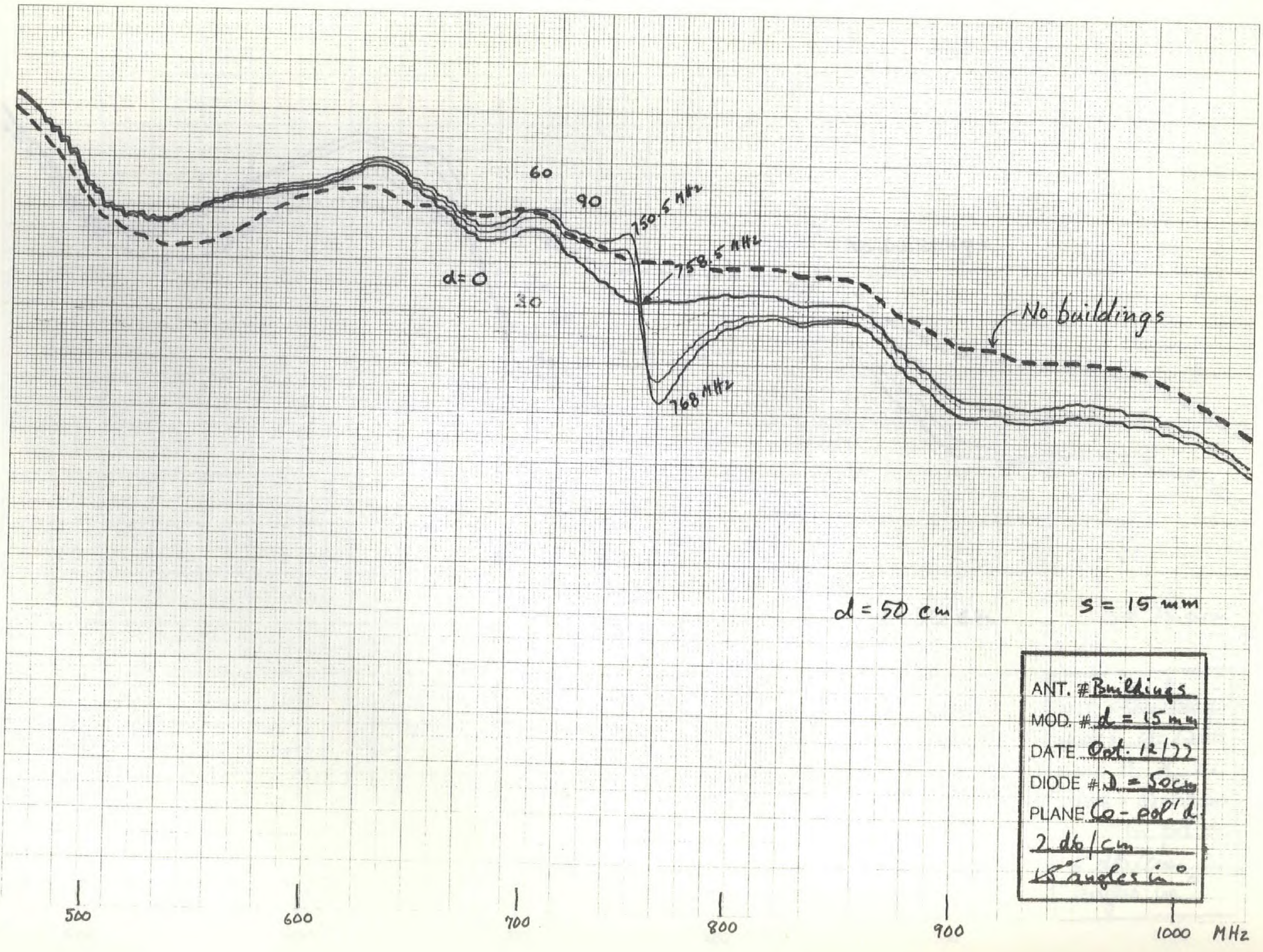
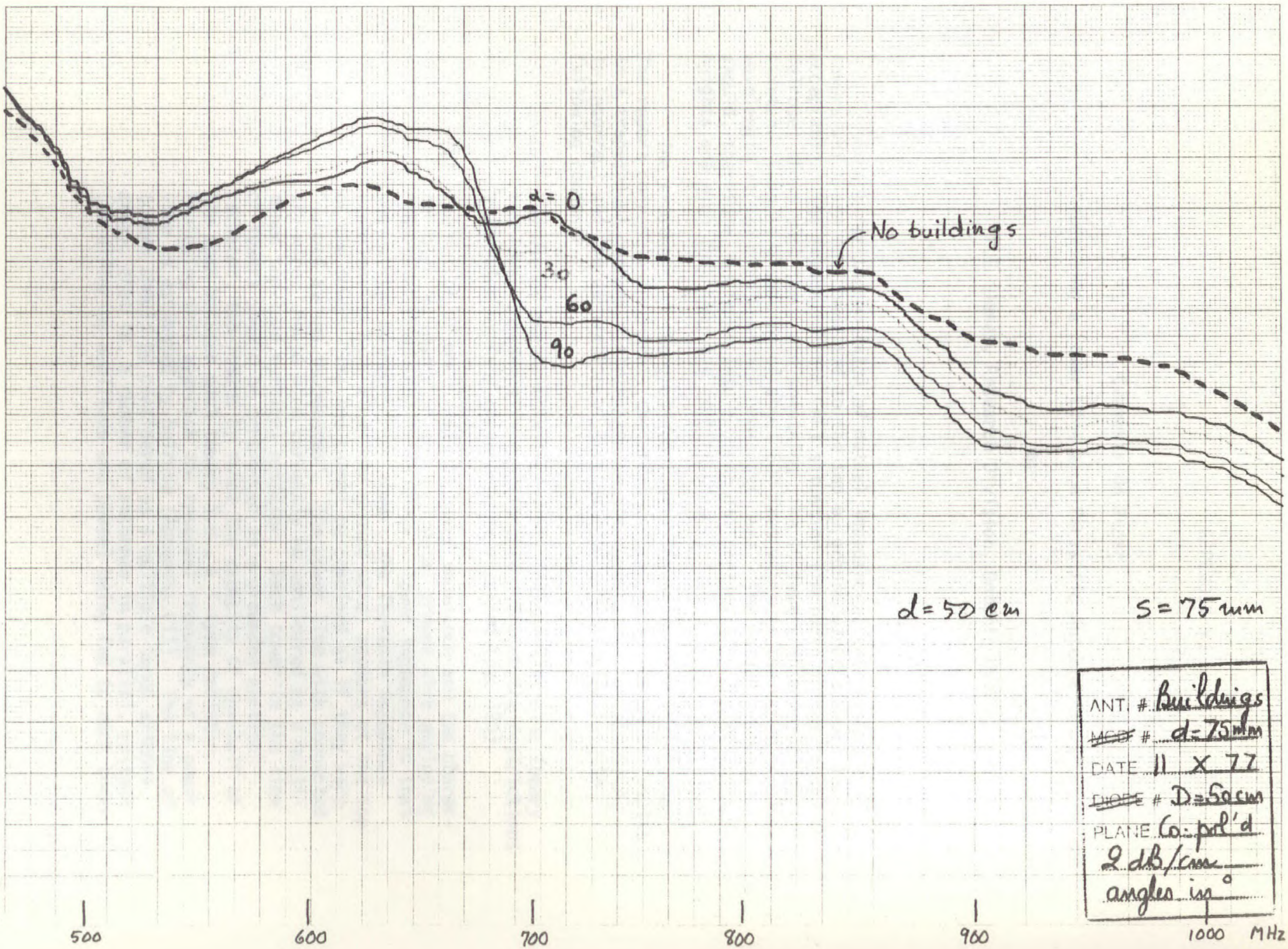

60
90
750.5 MHz
758.5 MHz
d = 0
30
768 MHz
No buildings
d = 50 cm
s = 15 mm
ANT. # Buildings
MOD. # d = 15 mm
DATE Oct. 12/77
DIODE # D = 50 cm
PLANE Co-pol'd
2 db/cm
Angles in °
500
600
700
800
900
1000
MHz

Fig. 17



d= 0
30
60
90
No buildings
d=50 cm
S=75 mm
ANT. # Buildigs
MOD # d=75mm
DATE 11 X 77
DIODE # D=50cm
PLANE Co-pol'd
2 dB/cm
angles in °
500
600
700
800
900
1000 MHz


Fig. 18

APPENDIX VI

## Comments On Paper

## "Modelling a Power Line as a Parasitic Antenna Array"

by

D.E. Jones, Research Division, Ontario Hydro

Except for the omission of mutual impedances, the treatment of towers which are not connected to the top by ground wires, appears to be acceptable. The sketch for the CHFI situation (included in the report by Belrose) shows that there are something like 10 towers in a one mile stretch. This is a spacing of about 500 feet which is the order of half-wavelength at the middle of the broadcast band. The mutual impedance should, therefore, be taken into account and particularly if the tower heights are such that they are near resonance.

The treatment of the grounded towers leaves much to be desired. The report correctly interprets the effect of the sky-wires which results in a trapezoidal current distribution on the towers, but the approach is incorrect and the derivation of the tower currents faulty for the following reasons:

(a) The use of the formula from King, Transmission Line Theory for Tower Impedance is questionable. One of the restrictions stipulated by King appears to be violated (pg. 120).

(b) The method of combining the tower impedance and the characteristic impedance of the horizontal ground wire employing "Thevenin Impedance" is in error. Tower impedance is that seen at the bottom of the tower, the Thevenin impedance (seen looking back along the ground wire) appears at the top of the tower. The two cannot be combined as if they were "lumped series impedances". The power line with connected sky-wires should more correctly be considered as a multi-tuned top-load vertical radiator. Each tower in the line of towers should be considered as a grounded vertical radiator, top-loaded by twice the capacity of one-half of the span between each tower; i.e., a T-type radiator. Employing this approach the resonant frequency of a power line is estimated by Belrose (Appendix VII). The line of towers should be considered as a multiple-tuned antenna array; that is, a number of antennae in parallel, voltage (in differing amplitude and phase) being fed to each tower through the flat-top (sky-wires) system (reference Laport, Radio Antenna Engineering, McGraw Hill, 1952, pp. 38-40). For n towers, the base impedance of the multiple-tuned antenna system would be quite high. The full explanation of multiple-tuning, as applied to the present configuration, is, however, much more complex than indicated by Laport.

(c) The same argument can be used to cast doubt on the implication that the current induced in a tower by the incident field and the currents flowing along the ground wires from each tower can be added together.

(d) No account seems to be taken of the fact that the incident fields at the different towers will, in general, be of different phases.

J.S. Belrose

15 July 1977

APPENDIX VII

## Calculation of the Resonant Frequency of a Power Line with Connected Sky-Wires

A power line with connected sky-wires can be consiered as: (1) a multiple tuned top load vertical radiator; or (2) a system of coupled loops where each loop comprises the vertical tower, the sky-wire, the adjacent tower and the return path through the ground.

Suppose we have a power line comprising towers of height 165 feet spaced 900 feet. Suppose the tower is of square configuration 10 feet on a side at the base of the tower and 3 feet on a side at the top of the tower.

First, let us consider the transmission line as a system of coupled full wave loops. The length L of a full wave quad loop is approximately

$$L(ft) = \frac{984}{f(MHz)}$$

Hence the resonant frequency

$$f(MHz) = \frac{984}{L(ft)}$$

For 165 foot high towers spaced 900 feet the loop length equals (165 + 900)(2) = 2130 feet, and so f(MHz) = 0.462 (or 462 kHz).

If the transmission line is considered as a multiple tuned top loaded vertical radiator, where each element of the system comprises a vertical radiator (the tower) top loaded by twice the capacity of one half of the sky-wire span between towers. The resonant frequency of the system can be calculated as follows.

The average cross-sectional area of the tower is 42.25 $ft^2$. A circular tower having this cross-sectional area would have a radius of 3.66 feet.

The characteristic impedance of the tower is estimated as follows:

$$Z_o^v = 138 \log_{10} \frac{2\, h_{av}}{a} \qquad (1)$$

where hav = average height of tower above ground = $\frac{165}{2}$

a = radius of equivalent circle having the same cross-sectional area as the tower = 3.66 feet.

$$Z_o^v = 138 \log_{10} \left(\frac{165}{3.66}\right) = 228 \text{ ohms}$$

With capacitive top-loading of the vertical tower, the reactance at the base of the tower, for a top-loading reactance X at a frequency f can be calculated from transmission line equations (ref. Laport)

$$X_a = Z_o^v \frac{X \cos H + j Z_o^v \sin H}{Z_o^v \cos H + j X \sin H} \qquad (2)$$

where H = electrical length of the tower without top-loading.

At the fundamental frequency of the system, $f_o$, $X_a = 0$, under which condition the numerator of Equation (2) must be zero, hence we can deduce the equivalent top-loading reactance for resonance, or if this is known the frequency at which resonance occurs.

$$X_o \text{ (for resonance)} = -j Z_o^v \tan Ho \text{ ohms} \qquad (3)$$

Suppose the sky wire of length $\ell$ (span length) is a single No. 4 wire (diameter = 0.204 inches). Let us guess that the sag is 25 feet (probably under estimated). The characteristic impedance of the horizontal sky wire is calculated from equation (1), but denoting this impedance as $Z_o^h$

$$Z_o^h = 138 \log_{10} \frac{2\ (152)\ (12)}{(.102)}$$

where 152 feet is the average height of the sky wire, and 0.102 inches the radius of the sky wire.

The reactance X of this wire is twice the reactance of one half the span (T-type top loaded radiator)

$$X = -j \frac{2 Z_o^h}{\tan \frac{L}{2}} \qquad (4)$$

where L = electrical length of span of length $\ell$

For resonance, substituting equation (4) in (3)

$$-j \frac{2 Z_o^h}{\tan \frac{L}{2}} = -j Z_o^v \tan H \qquad (5)$$

The length in feet for a free-space wave length at a frequency f is

$$\frac{984}{f(\text{MHz})} \qquad (6)$$

Therefore for $\ell$ = 900 feet (add 5% for end effects)

$$\frac{L}{2} = \frac{900\ (1.05)}{2} \times \frac{f}{984} \times 360^{o} = 172.86\ f \text{ degrees}$$

and for a tower of height h = 165 feet (add 5% for end effects)

$$H = 165\ (1.05) \times \frac{f}{984} \times 360^{o} = 633.84\ f \text{ degrees}$$

Therefore, substituting in Equation (5)

$$\frac{2\ (628)}{\tan\ (172.86\ f)} = 228 \tan\ (633.84\ f)$$

$$\tan\ (172.86\ f) \quad \tan\ (633.84\ f) = \frac{2\ (628)}{228} = 5.508$$

This equation can be solved by interation

$$f = 0.389 \text{ MHz } (389 \text{ kHz})$$

which is the self resonant frequency of the power line considered as a vertical radiator.

If more than one wire is used for the sky wire(s), the capitive loading will be greater, and the self resonant frequency lower ...... a desireable situation, since if both the fundamental frequency (quarter wave resonance frequency) and the frequency for which half wave resonance occurs lie below the broadcast band the effect on AM broadcast radiators will be greatly reduced over the situation where a resonance situation at the AM broadcast frequency could exist.

John S. Belrose
19 July 1977

APPENDIX VIII

## Detuning Transmission Lines as Radiators of AM Broadcasting Signals

A transmission line comprising grounded towers connected by overhead "ground" or sky wires can be considered as a multiple tuned top loaded vertical radiator. If the resonant frequency of the system considered as a medium-frequency antenna system lies in the AM broadcast band, and if the power line is located near a broadcast station, re-radiation from it could result in serious distortion of the directional pattern of the broadcast antenna array.

Since the magnitude of the re-radiation effect will be strongest when the transmission line is resonant, it is necessary, before considering methods to detune the power line, to measure the resonant frequency of the system. How can this be done?

Before we consider how to measure the resonant frequency of the power-line, let us discuss some pertinent aspects of vertical radiators which are not well known (the author of this note has not seen what follows published in the scientific literature). The sketch in Fig. 1(a) shows an insulated base T-Type radiator, which is the common

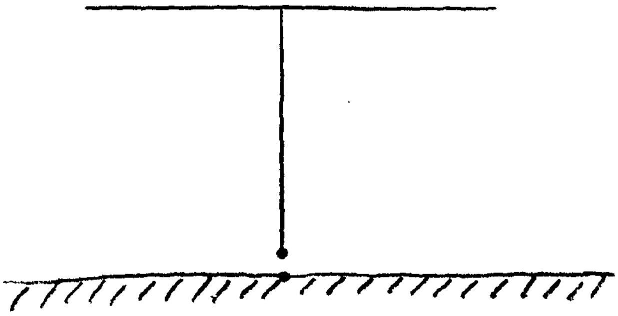


Fig. 1(a) Insulated base T-type radiator

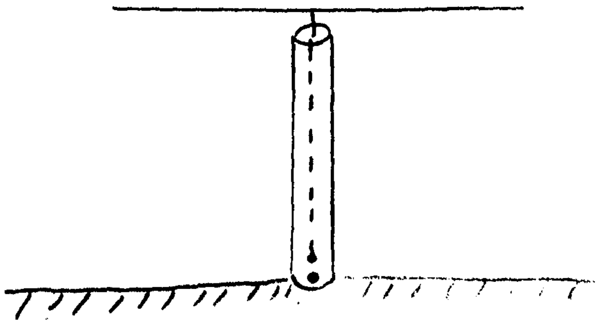


Fig. 1(b) Grounded base T-Type radiator

arrangement. Power is applied to base of the radiator through suitable matching circuitry, between the base of the antenna and ground. The sketch in Fig. 1(b) shows how the same antenna could be driven if the vertical radiator were a grounded tower. This is a very convenient method to feed a grounded tower radiator, and provided the capacitive top loading of the vertical radiator is not too small, the antenna radiates as well as the insulated base type. This is because the standing wave inside of the tower is coupled to the outside of the tower by the capcity of the top loading to the tower and to ground. This arrangement provides a means of measuring the resonant frequency of a transmission line, and also of tuning the system.

If the sky wire at the top of one of the towers is isolated from that tower, and earthed through a wire connected to it that runs down the centre of the tower to ground, then an RF impedance bridge can be connected between the bottom end of this wire and ground (ground should at the least comprise four radial wires connected to the four grounded legs of the tower). The impedance of the multiple tuned system can therefore be measured. The resonant frequency of the system can be lowered if each tower is similarly treated, and if the ground ends of the wires that earth the sky wire at each tower are "grounded" through an inductance, in the manner sketched below. This permits the sky wires to be grounded at each tower, and the towers are also grounded, yet the grounded towers can be effectively tuned.

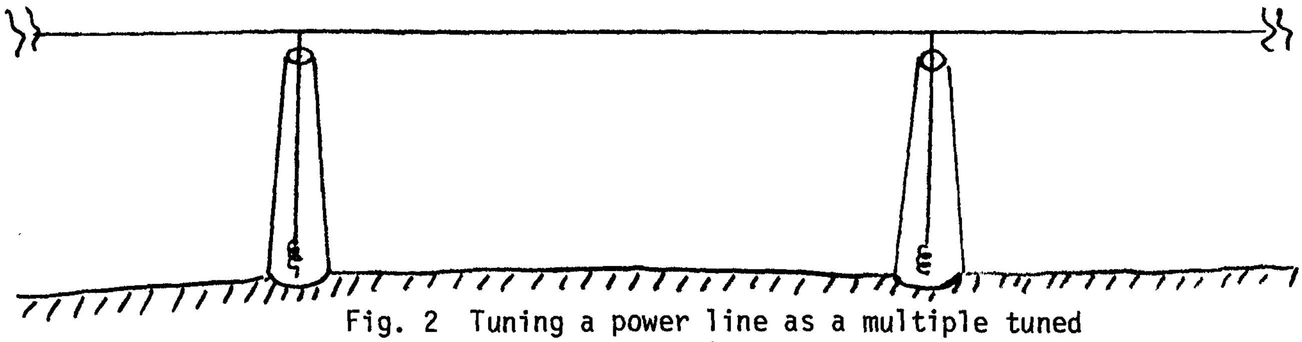


Fig. 2 Tuning a power line as a multiple tuned antenna

While this method of tuning power lines has not been tried, it should work very effectively compared with methods commonly used such as tuned stubs attached as out riggers to the legs of the tower. The latter does not change the resonant frequency of the whole system, but only tries to provide a high impedance for currents flowing on particular towers. The method described above actually tunes the total power line system, and it should be possible to lower the resonant frequency of the power line such that the resonant frequencies, for quarter and half wave resonance, lie below the broadcast band.

John S. Belrose

19 July 1977