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January 22, 1993

MEMORANDUM

TO: R. Rackley, D. Everist, R. Eckert,

FROM: J. Hatfield/B. Dawson

The attached document represents an effort to describe power line re-radiation and remediation effects vis a vis AM antenna systems. Since it is going to appear under the aegis of the IEEE Power Engineering Society, the utility folks are likely to accord it scriptural reverence.

We feel that it has some very serious misstatements and errors, and needs to be revised extensively. Unfortunately, none of the contributors to it appear to have any practical knowledge or even very extensive theoretical knowledge of the subject.

We are preparing a set of fairly extensive comments, and will send them along to you. Unfortunately, the Corona Effects working group of the PES is meeting next on February 2, and so it would be nice if you could review this document and, if you feel as we do, send at least a short letter or memorandum expressing your misgivings to:

James Stewart, P.E., Chairman
Power Line Re-radiation Task Force, PES, IEEE
Power Technologies Inc.
1482 Erie Blvd.
Schenectady, NY 12301-1058

and if you have an extra stamp:
Thos. J. McDermott, Chairman
Corona and Field Effect Subcommittee, PES, IEEE
New York Power Authority
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Thanks

S. Mooney

GUIDE ON THE PREDICTION, MEASUREMENT AND ANALYSIS OF AM BROADCAST RERADIATION BY POWER LINES

Prepared by

Task Force on Power-Line Reradiation belonging to the Corona Effects Working Group of the Corona and Field Effects Subcommittee of the Transmission and Distribution Committee of the IEEE Power Engineering Society

P1260/D5
January 10, 1992

ABSTRACT

This document provides a set of procedures to be followed to cope with reradiation of AM broadcast signals from power lines and other large metallic structures. Reradiation may be described as electromagnetic waves radiated from a structure which has parasitically picked up signal from the environment. A simplified prediction technique called a survey is described to determine which structures could possibly cause a problem. Guidelines for measurements and data analysis are also included.

Table I Task Force and Contributor List

At the time this draft of the guide was completed, the Task Force on Power-Line Reradiation had the following membership:

Rick C. Madge, Chair	James R. Stewart
Jean Provost	Michael A. Reavis
Tom McDermott	Rod S. Baishiki
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Other individuals who have contributed review and comments are:

Mark A. Tilston	Tom Young
Attila Paldi	Magda Hammam

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1. INTRODUCTION

1.1 Disclaimer

The purpose of this document is to provide a set of procedures to be followed to cope with reradiation of AM broadcast signals from power lines and other large metallic structures. While the procedures may be applicable to reradiation problems from other medium frequency (MF) sources, such as navigation beacons, they are not intended to be applied to reradiation problems from higher frequencies such as television. It is anticipated that this document will be used by owners of potentially reradiating structures, and radio stations. It is not designed to be applied as legal evidence of harmful effects of a reradiating structure upon an AM broadcasting station.

1.2 Description

Radio stations are generally located near large populations. This may put them close to metallic structures (buildings, power lines, antennas) which are a quarter wavelength tall (140 to 47 m) somewhere in the AM broadcast band, 535 to 1605 kHz. This means they can efficiently pick up and rebroadcast an AM radio signal, affecting the desired broadcast pattern. A decrease in received signal can mean a loss of listeners for the station, while an increase can result in interference to stations servicing other areas.

Reradiation may be defined as follows:

> "A radio station antenna radiates electromagnetic waves. As these waves travel outward from the antenna, they may meet various man-made structures containing metal. The waves induce electrical current to flow in the metal. This induced current radiates its own electromagnetic waves at the same frequency as the radio station. The waves produced by the induced current are called reradiation."[2]

An AM broadcast array consists of 1 or more antennas fed the same broadcast signal but at different current levels and with different delays. By carefully choosing the height, location, current level and delay for each antenna, a far field pattern can be constructed to broadcast strongly in some directions (when the signals from the antennas are additive) and weakly in others (when the signals from the antennas tend to cancel each other). The strong signals are generally directed toward the local listening area in what is called the major lobe. Other smaller listening areas can be serviced with strong signals in minor lobes. The weak signals, called nulls, are generally directed at areas without listeners, or towards other stations operating at the same frequency (co-channel), at the next highest or lowest frequency (adjacent channel) or 2 channels away (2nd adjacent channel). The signal must be weak towards these stations so as to avoid interference with their listeners.

A pattern null can be generally defined as any portion of a pattern where the theoretical signal levels are less than 10% of the published RMS value of that pattern. A pattern can have any number of nulls.

In the case of a power line, reradiation is directly proportional to the AM current in its towers, which is in turn dependent on the tower design and tower spans. If a loop, consisting of two towers, the span between them (providing at least one overhead ground wire is present), and the ground image, is a multiple of the wavelength of the AM station, then a resonance may be set up which causes high current to flow. In some circumstances the loop distance to the second or third tower over can also be of concern.

For power lines without skywires, or when skywires are insulated from the tower, the tower height and shape become the prime factors. The electrical height of a tower is typically 15% higher than the physical height due to the top loading effect of the conductor cross-arms. As quarter wavelengths ($\lambda/4$) of AM stations are 47m to 140m, there is great potential for resonant, or $\lambda/4$, high towers.

The effective radius of a structure strongly affects the radiation resistance, and therefore the efficiency of the tower as an antenna. For steel towers the effective radius is typically 3 to 4 metres. For wood pole lines the effective radius of the grounding wire is as little as 0.01 m, resulting in a higher radiation resistance, lower parasitic current, and therefore less reradiation.

Computer programs can be used to predict the reradiation effect. Moment-method programs use a rigorous approach and typically run on a mainframe. The number of towers that can be simulated is limited due to the complexity of the program. Transmission-line method programs run on desktop computers and use a simpler approach. They can therefore model many more towers.

None of the computer programs provide the degree of accuracy required by the standards and procedures governing radio stations. These standards and procedures have been issued and developed by the countries that signed the North American Regional Broadcasting Agreement. Computer programs are helpful in indicating which situations might cause trouble, and which structures would be ideal candidates for remedial measures.

Parasitic current is often seen during the construction phase of a new line near a high power antenna array. The construction crane, tower segments and the worker can create a resonant loop, causing high levels of RF current to flow. This can cause serious RF burns to the worker. Likewise, the presence of tuning stubs on a tower can cause high levels of RF current to flow, creating a safety hazard.

1.3 Proof of Performance

When an AM radio station applies for a license, the proposed radiation pattern must be provided. After the brief has been accepted and the installation completed, measurements must be made to ensure that the practical pattern agrees with the proposed one. This process is called a Proof of Performance.

Ratio measurements is a common method radio stations use to establish the shape of a pattern for a Proof of Performance. The ratio method involves taking field strength measurements around the station in two conditions. The first involves the normal connection of the transmitter to the array. The second, commonly called an omnidirectional, involves connecting the transmitter to one antenna only. Assuming there are no significant reradiators, the omnidirectional pattern should be circular in shape. Therefore the ratio between the first directional pattern to the second omnidirectional pattern yields the true shape of the directional pattern and is independent of ground conductivity.

The ratio method involves taking measurements about 15° apart in the far field. The far field for an array, roughly estimated as 10 times the largest array spacing, is usually less than 5 km. Since the pattern to quantify is usually a smooth and regular shape, the 15° spacing is usually sufficient. Ratio tests are usually completed in a few days or weeks, ensuring that changes in ground conductivity and nearby construction are kept to a minimum.

The presence of reradiators complicates the issue. The far field including reradiators can be as large as 50 to 100 km, too large for practical measurements. In addition, the pattern shape becomes rougher and more measurements need to be taken, roughly every 5° apart instead of 15°. Also, the time lapse between the beginning of the construction of the potential reradiator and its end, can be in the order of years. Therefore, changes in the surrounding area will be much greater than during a regular proof of performance.

For these reasons, the regular proof of performance is not adequate to deal with cases where reradiation may be present. For the same reasons, proof of performance tests should never be used as proof that no problem existed before any construction.

It can also be added that a proof of performance is goal-oriented, in that the station *must* prove their pattern using whatever means possible. The purpose of a reradiation investigation is quite different, and it can be easier to attribute problems to reradiators, than achieve the pattern.

2. AM RERADIATION GUIDELINES GENERAL PROCEDURES

The guidelines have been divided into two categories: potential problems, and existing problems. The two situations require different handling due to the difference in availability of proper data. A brief description of each step of the guidelines in included in this section. More detailed explanations of each is included in later Sections. The background considerations have been covered at length in the publications and can be found in the Bibliography.

2.1 Potential Reradiation Problems

The following is a general procedure to follow to investigate potential reradiation from proposed structures. Details on each step will be presented in following sections.

1) Simplified Prediction (Section 3)

The potential reradiation from the structures should be analyzed using either an accepted computer program or the survey technique. Should the prediction indicate that a problem is possible, the affected groups should get together to discuss a future plan of action.

2) 'Before' Field Strength Measurements (Section 4)

At least three sets of field strength measurements of the pattern should be carried out prior to construction of the structures. Two of the tests should be taken in quick succession in one ground conductivity extreme, with the third test taken in the other extreme. For the reasons outlined in Section 1.3, a Proof of Performance for the station may not be used as the 'before' pattern.

3) Remedial Measure Design (Section 7)

Possible remedial measures should be investigated in advance of construction of the structures. The final design of the structures should then take into account the fact that these remedial measures may be incorporated.

4) 'After' Field Strength Measurements (Section 4)

At least one set of field strength measurements, and preferably more, should be carried out after construction of the structures. The test(s) should be carried out in ground conductivity conditions as similar as possible to one of the 'before' tests.

5) Field Strength Measurement Analysis (Section 5)

The analysis should factor out as many variables as possible, leaving just the effect of the reradiator. If the effect is small enough to be ignored, then the investigation may stop here.

6) Structure Reradiation Measurements - optional (Section 6)

Reradiation measurements of the structures may determine if they are radiating a high amount of the AM signal. This information may identify structures most likely to require remedial measures.

7) Remedial Measures or Alternatives (Section 7)

Appropriate remedial measures or alternatives may be exercised. Field strength measurements should be made to verify the effectiveness. Alternatives to remedial measures may include relocating the structure(s) or radio station, changing frequency or pattern, altering the structure design, or accepting the consequences of distortion.

2.2 Existing Reradiation Problems

The following is a general procedure to follow to investigate potential reradiation from existing structures. Details on each step will be presented in later Sections.

1) Simplified Prediction (Section 3)

The potential reradiation from the structures should be analyzed using either an accepted computer program or the survey technique. Should the prediction indicate that a problem is possible, the affected groups should get together to discuss a future plan of action.

2) 'After' Field Strength Measurements (Section 4)

At least three sets of field strength measurements should be carried out. Two of the tests should be taken in quick succession in one ground conductivity extreme, with the third test taken in the opposite extreme. For the reasons outlined in Section 1.3, a Proof of Performance for the station may not be used as the 'before' pattern.

3) Field Strength Measurement Analysis (Section 5)

The analysis should factor out as many variables as possible, leaving just the effect of the reradiator. The lack of proper 'before construction' measurement will make this difficult. If the effect is small enough to be ignored, then the investigation may stop here.

4) Structure Reradiation Measurements - optional (Section 6)

Reradiation measurements of the structures may determine if they are radiating a high amount of the AM signal. This information may identify structures most likely to require remedial measures.

5) Remedial Measure Design (Section 7)

If a problem appears to exist then remedial measures should be investigated. The predictive programs should be able to include in their analysis, various remedial measures and their effect.

6) Remedial Measures or Alternatives

Appropriate remedial measures or alternatives may be exercised. Field strength measurements should be made to verify the effectiveness. Alternatives to remedial measures may include relocating the structure(s) or radio station, changing frequency or pattern, altering the structure design, or accepting the consequences of distortion.

3. RERADIATION PREDICTION TECHNIQUES

A reradiation prediction technique is useful in determining whether any given situation could present a problem, and what remedial measures may be effective. Two techniques are available: computer programs, and structure surveys.

Computer programs are relatively accurate but require access to the program, and some expertise in interpreting the results. The survey technique is quick, self-explanatory, and is included as part of this document. However, the simplicity of the survey technique necessitates a sizable margin for error, and many structures may be erroneously flagged as damaging reradiators. Used alone, the survey technique could lead to considerable time and money spent in tracking down 'innocent' structures.

It is therefore strongly recommended that any survey indicating problems be followed by the use of one of the prediction programs. The survey technique on its own should not be used to establish the necessity for a costly testing program.

3.1 Computer Programs

Appendix A includes a list of some of the available computer programs. Two methods of predicting the effects of power lines on AM radiation patterns are currently being used, and they model power line towers in completely different ways.

The ***moment-method*** models structures as a collection of wire segments each less than a tenth of a wavelength long. The current in each segment is approximated by a set of current distributions with unknown strengths. The strengths are then solved to satisfy boundary conditions. Field intensity levels at any location can be calculated as the sum of the signals radiated from each segment. Because of their complexity, these programs are limited to analyzing about 40 towers and are typically run on mainframes.

The ***transmission-line*** method treats the skywire and its image in the ground as a transmission line connecting the towers. Each tower parasitically picks up a level of current dependent upon the signal incident on it, and the skywire distributes this current according to the various tower and skywire impedances. Field intensity levels can be calculated as the sum of the signals radiated from each tower. These programs can be run on desktop computers and can handle hundreds of towers.

All programs require information concerning the broadcast antenna array, power-line parameters and tower locations, and other significant reradiators in the immediate area. The exact location of power line towers is desirable, but not necessary. Unevenly spaced tower locations can be estimated, thus preventing false resonances or antiresonances. The utility project engineer should know the approximate span lengths and variations, and the approximate tower heights and variations.

A before pattern should be computed using the antennas *and any existing reradiators*. An after pattern should then be computed by adding the structure(s) in question. A potential problem exists if:

a) the before pattern meets the pattern limitations and the after pattern does not; or
b) the before pattern falls outside any of the pattern limitations and the after pattern falls significantly farther outside them.

3.2 Survey Technique

The survey technique can be used to determine which structures in the area surrounding the AM broadcast antenna array could possibly cause distortion to the AM radiation pattern. Power lines, communication towers, and buildings should be considered.

First the minimum pattern tolerance must be determined. The theoretical radiation pattern of the radio station is compared with the upper and lower pattern limitations. An upper limitation is the maximum permissible radiation toward the service area of another station; a protection. A lower limitation is the minimum permissible radiation toward a station's own service area (coverage). The methods of computing these limitations are covered in the Canadian Department Of Communication rules and regulations. *The minimum pattern tolerance is the minimum value of the difference between the theoretical pattern and either of its limitations.*

To simplify the procedure, each structure is considered independently of the other structures, and independently of existing levels of reradiation. Due to real-world effects, potential reradiators more than 10 km away should be ignored. It is strongly recommended that a survey resulting in possible problems be followed by the use of a prediction program to determine whether further study is necessary. Appendix B contains an example of the reradiation survey technique.

The following equation is used to determine the maximum permissible structure dimensions, as outlined in Table 2. The reradiation ratio represents the percentage of incident field which when reradiated will equal the minimum pattern tolerance.

$$r = \frac{Tol_{min} \times Dist}{Field \times \lambda}$$

where r is the reradiation ratio

Tol_{min} is the minimum pattern tolerance

Dist is the distance to the reradiator in m

Field is the 1 km unattenuated field strength in the direction of the reradiator

λ is the wavelength of the radio station signal in metres

Table 2 Maximum Allowable Reradiator Dimensions as a Function of Reradiation Ratio

Reradiation Ratio	Maximum Structure Height in metres	Maximum Power Line Loop Length in metres
$r > 0.2$	Structure is acceptable	Power line is acceptable
$0.1 < r \leq 0.2$	$r \lambda$	$(0.94 + 0.3 r) \lambda$
$0.02 \leq r < 0.1$	$(0.025 + 0.75 r) \lambda$	$(0.76 + 2 r) \lambda$
$r < 0.02$	0.04λ	0.8λ

4. FIELD STRENGTH MEASUREMENTS

Field strength measurements are the final determination in whether a radio station is meeting its pattern limitations, or if a structure is distorting an AM pattern. Computer programs do not yet have the complexity or sophistication to model the real world effects that interact to create an actual radiation pattern.

There are three basic methods that can be used to take field strength measurements: ratio, circular and radial. A brief description of each follows.

The ***Ratio*** between a reading in the directional mode to a reading taken at the same location in the omnidirectional mode is commonly called a ratio measurement. This is a valid method of determining the pattern shape of the antenna array, only if the omnidirectional is circular or has a known shape to allow correction of the ratios obtained. Because the directional and omnidirectional patterns can induce different levels of current in nearby reradiators, the ratio method can lead to errors in determining the effect of reradiators.

Circular measurements involve taking closely-spaced measurements at a constant radius from the broadcast array. The radius should ideally be in the far field of the antenna array and any potential reradiators. By taking measurement sets in widely different ground conductivity conditions, it is possible to observe the effect of ground conductivity.

Radial measurements consist of taking up to 20 closely separated measurements on a radial line extending out from the transmitter site to the 0.5 mV/m contour. Usually a minimum of 8 radials are required for a final Proof of Performance, and one for a Supplementary Proof. The purpose is to determine the conductivity, the contour locations and the inverse-distance unattenuated field. The presence of reradiators can strongly affect this method, as readings taken near the transmitter will be less influenced by reradiators than readings taken near reradiators. This affect would distort the radial profile. Roughly 160 measurements (8 radials × 20 measurements/radial) are required for a full set of radial measurements at 45° apart. As reradiation investigations require measurements at most 5° apart, the radial approach rapidly becomes impractical.

The proper choice of measurement technique is dependent on the general terrain in the area around the broadcast array. The choices can be broken down as follows:

a) Mountainous terrain

Severe elevation changes in the terrain can strongly affect propagated signals. Therefore, if severe elevation changes exist in the path of critical signals, then a combination of ratio and radial measurements will have to be used. Section 4.2 describes the techniques.

b) All other cases

Circular measurements are the preferred method of determining the reradiation effect of any reradiators for all other cases. At least one radial measurement will be necessary to determine the prevailing ground conductivity.

4.1 Circular Measurements

Circular measurements are the best method of accurately quantifying the changes to an AM broadcast pattern assuming an absence of severe changes in elevation. This method includes near-field measurements for monitoring antenna parameters, and far-field measurements to identify the pattern shape.

Circular measurements generally consist of about 80 closely-spaced pattern test points, all roughly the same distance away from the antenna array (test radius), plus up to 24 near-field test points. A general far-field approximation is $2d^2/\lambda$, where d is the largest separation between elements in the array plus reradiators, and λ is the wavelength. However, this can easily be an unreasonable distance i.e. d = 3 km, λ = 200 m leads to far field ≥ 90 km. *Therefore, the test radius is defined as 90% of $2d^2/\lambda$, but no more than 30 kms.* To minimize errors in the analysis, all test points should be as close as possible to the test radius.

At least one ground conductivity radial must be taken to determine the prevailing ground conductivity. Where significant differences in ground conductivity can be expected in different directions, a radial should be taken in each direction of concern.

Circular measurement test points should be spaced no more than 4-5° apart to quantify rapid rates of signal variations. The only exception may be in the main lobe of the pattern, where test points can be more widely spaced only if there is no concern with distortion to the pattern coverage. Additional points may be desirable in sensitive null portions. Test points should be selected according to the Test Point Selection guidelines in Section 4.3.

4.1.1 Description of Measurement Sets

If the potential reradiator has not yet been built, then at least three sets of circular measurements should be made before its construction, and at least one set after construction.

1. *Measurement set B1* - taken in one of the ground conductivity extremes, either very wet or very dry.
2. *Measurement set B2* - taken in the opposite ground conductivity extreme as set #1.
3. *Measurement set B1a or B2a* - taken immediately after either set B1 or B2 to quantify the typical levels of pattern variation.
4. *Measurement set A1* - taken soon after construction, and in ground conditions similar to one of the before construction tests.
5. *Measurement set A2 (optional)* - taken in the opposite ground conductivity extreme as set A1.
6. *Measurement set A1a or A2a (optional)* - taken immediately after either set A1 or A2 to quantify typical levels of pattern variation.

If the potential reradiator has already been built, then at least three sets of circular measurements must be performed.

1. *Measurement set A1* - taken in one of the ground conductivity extremes, either very wet or very dry.
2. *Measurement set A2* - taken in the opposite ground conductivity extreme as set A1.
3. *Measurement set A1a or A2a* - taken immediately after either set A1 or A2 to quantify typical levels of pattern variation.

4.2 Ratio Measurements

Ratio measurements may be necessary in areas where severe elevations changes significantly affect the signal propagation path in certain directions. This method includes near-field measurements for monitoring antenna parameters, and directional and omnidirectional measurements to identify the pattern shape.

Ratio measurements generally consist of about 80 closely-spaced pattern test points plus up to 24 near-field test points. Each pattern test point should ideally be in the far field, although test points closer to the array may be necessary to keep severe elevation changes out of the propagation path. A general far-field approximation is $2d^2/\lambda$, where d is the largest separation between elements in the array plus reradiators. However, this can easily be an unreasonable distance i.e. d = 3 km, λ = 200 m leads to far field ≥ 90 km. Therefore, test points should be between 5 km and 30 km from the array where possible.

The signal level at each test point will be measured during the omnidirectional mode and during the directional mode. The omnidirectional mode involves feeding the broadcast signal into only one antenna. If possible, the other antennas should use filters to prevent reradiation from distorting the omnidirectional pattern. The directional mode involves connecting the antennas in the normal broadcasting configuration.

Ratio measurement test points should be spaced no more than 4-5° apart to quantify rapid rates of signal variations. The only exception may be in the main lobe of the pattern, where test points can be more widely spaced only if there is no concern with distortion to the pattern coverage. Additional points may be desirable in sensitive null portions. Test points should be selected according to the Test Point Selection guidelines in Section 4.3.

4.2.1 Description of Measurement Sets

If the potential reradiator has not yet been built, then at least three sets of directional and omnidirectional measurements should be made before its construction, and at least one set after construction.

1. *Measurement set B1* - taken in one of the ground conductivity extremes, either very wet (or snow covered), or very dry.
2. *Measurement set B2* - taken in the opposite ground conductivity extreme as set #1.
3. *Measurement set B1a or B2a* - taken immediately after either set B1 or B2 to quantify the typical levels of pattern variation.
4. *Measurement set A1* - taken soon after construction, and in ground conditions similar to one of the before construction tests.
5. *Measurement set A2 (optional)* - taken in the opposite ground conductivity extreme as set A1.
6. *Measurement set A1a or A2a (optional)* - taken immediately after either set A1 or A2 to quantify typical levels of pattern variation.

If the potential reradiator has already been built, then at least three sets of directional and omnidirectional measurements must be performed.

1. *Measurement set A1* - taken in one of the ground conductivity extremes, either very wet (or snow covered), or very dry.
2. *Measurement set A2* - taken in the opposite ground conductivity extreme as set A1.
3. *Measurement set A1a or A2a* - taken immediately after either set A1 or A2 to quantify typical levels of pattern variation.

4.3 Test Point Selection Criteria

Quality test points are necessary for accurate measurements. The nature of the field strength analysis is to look at the areas of most severe distortion. Substandard test points can result in erroneous distortion that can become the focal point of the analysis.

Test points should be reviewed every time a new set of measurements is taken. While the greatest care and time will be spent establishing the test points the first time round, various events can occur later to effectively eliminate a test point from further use. New construction is the most common reason for test point elimination. It is for this reason that too many points are better than not enough. Care should be taken to choose test points away from where new structures will be built.

For the purpose of analysis, questionable test points are used but flagged in case they result in serious distortion. Unacceptable test points are not used in any form. Unacceptable test points may be replaced with new nearby acceptable test points, but direct comparisons with measurements taken at the previous point are disallowed.

The following set of guidelines will help to control factors leading to unnecessary errors:

1) Measurements should always be performed by at least two operators. Each operator should use a recently calibrated field strength meter. The cause of any significant differences between readings at a test point should be determined before any test point can be considered acceptable. These differences should not be confused with calibration differences between meters (which should remain somewhat constant throughout the test) or normal measurement error (which should not exceed 5%).

2) Operators should observe the received signal strength within a 20 metre radius of the precise test point location. Variations of 5% or more indicate an unacceptable test point. Variations of between 3% and 5% should be noted and the test point flagged as questionable.

3) By rotating the meter antenna, the ratio of the maximum signal obtainable to the minimum signal obtainable should be at least 10:1. Also, the minimum signal should be roughly 90° to the maximum. A deviation from either of these criteria can indicate that local structures are affecting the measurement. An exception to this rule is for signal strengths of less than 0.5 mV/m where ambient noise levels or distant radio station signals can cause the minimum signals to exceed 10% of the maximum. If the interference is caused by skywaves, which can occasionally be present during the day, the reading should be repeated at the next opportunity when the interference is less severe. Another exception is for measurements taken in the near field of the antenna array where the far field signals are not yet formed. This can cause the minimum signal to be other than 90° to the maximum signal.

4) All test points should be in visually acceptable locations. There should be no large buildings, antennas, towers or other metallic structures in the immediate vicinity. There should be no evidence of buried pipes or cables. All wire fences should be at least 20 metres away. The distance to all overhead communication and wood-pole power lines should be at least 50 metres. The distance to steel-tower power-line structures should be at least 1 km.

5) All test points should be as close to the chosen radius as possible. Significant variations from this will add a further uncertainty, as the analysis requires scaling all readings to the test radius according to the prevailing ground conductivity.

6) The selection of test points should take into account the location of any planned construction that will interfere with future tests. In particular, test points should stay well clear of the site of the proposed structure being investigated. Pictures of each test point should be taken, with detailed descriptions made to ensure that the exact location can be found later.

7) Measurements should take place after sunrise and before sunset only, as nighttime interference levels are generally much higher than daytime ones. The effect of skywave interference should be watched during dawn and dusk hours. Measurements should also not be taken while it is raining or during severe icing conditions as it may affect the transmitter site and thereby alter the pattern.

8) Where line-of-sight to the antenna site is possible, the maximum signal should be obtained toward the array. A maximum reading away from the array is indicative of reradiation at either at the transmitting or the receiving antenna.

Test points meeting these conditions generally take time to locate. However, in some heavily industrial or urban areas these conditions may not be present. The decision is then how far to stray from the test radius to find a suitable location. An unacceptable test point should not be used even if it means abandoning a particular azimuth.

4.4 Near-Field Measurements

A potentially weak aspect of the circular test method is that changes in the antenna array will cause changes in the measured pattern which could be attributed to reradiators. To minimize this problem, a minimum of 24 near-field measurements must be taken to ensure a consistent pattern. The test points should cover all of the directions of concern.

The near-field measurements should be taken close to the antenna array to minimize ground conductivity effects, and far enough to have established a stable pattern. As a guideline, the distance should never be less than 1 km and never more than 5 km.

4.5 Ground Conductivity Radial

Analysis of the field strength data involves scaling all readings to a particular radius according to the prevailing ground conductivity. At least one radial in a direction of typical ground conditions must be performed as part of each measurement set. The radial should not pass close to any reradiators. Additional radials may be necessary in directions where the ground conductivity is believed to be significantly different than the typical one.

Radial measurements should be taken along one particular azimuth, starting at roughly 1 km from the antenna array and extending to 25% past the radius of the far-field measurements. At least 10 measurements should be taken, with each test point adhering to the test point selection criteria from Section 4.3. The deviation from the chosen azimuth should be as small as possible, with the acceptable deviation dependent on the rate of change of the pattern. Where the pattern is quite stable for at least 5° on either side of the chosen azimuth, test points may deviate from the radial by up to 1°. Where the pattern is rapidly changing, test points must stay within a fraction of a degree of the chosen azimuth. For this reason, radials should be chosen to run through azimuths where the pattern level is relatively constant.

The points from the radials should be plotted on a log/log graph with appropriate ground conductivity curves for that frequency overlaid. The conductivity most closely tracking the measurements can then be used in the distance scaling routine for data analysis, as outlined in Section 5.

An alternative to the above criteria for running a radial is to put the radio station on an undistorted omnidirectional pattern and then take radial measurements. The whole pattern would then be stable, and variations of 1 or 2°s should make no difference. This is especially valuable for radials that must be taken in the direction of a deep null.

4.6 Factors Affecting Measurements

Many factors other than reradiation can affect the received field strength signal.

Ground conductivity. A small change in ground conductivity can cause a large change in the signal strength depending on the frequency and distance from the antenna. For this reason, ground conductivity radials must be performed during the tests.

Propagation. Propagation refers to the way electromagnetic waves travel from one point to another. Since the distances to the test points are large, we must take into account shadow losses caused by terrain elevations, absorption of signal when travelling over heavily populated areas, and multiple changes in ground conductivity between the transmitter and the test point.

Antenna parameters. Fluctuations in the current ratios and phases can be caused by changes in ground conductivity, temperature, icing, or other factors. A deteriorated ground system will worsen the situation. Highly directional arrays have the greatest chance of being affected, as the parameters will have little tolerance.

Power output. Power output can vary with line voltage and antenna parameter variations. The latter will cause a change in the common point impedance, thereby causing a power change. Power changes can even occur with humidity and temperature changes throughout the day, making periodic logging impractical.

Interference. Noise and co-channel interference can affect weak signals. The night-time interference is usually much worse than daytime interference, and is worse in the fall. For this reason authorization should be obtained to operate the night pattern during the day for measurement purposes.

5. FIELD STRENGTH ANALYSIS

Analyzing field strength measurements involves analysing individual test measurements and comparing separate test results. Individual test analysis reduces the raw data to a set of field strength values at a constant radius (circular method), or a set of ratios of directional to omnidirectional readings (ratio method). Test-to-test comparisons may be used to calculate typical signal fluctuations (comparison of tests taken in quick succession), seasonal signal fluctuations (comparison of tests taken in opposite ground conductivity conditions), and structure insertion effect (comparison of tests taken before and after construction of the structures). As outlined in Section 1.3, a Proof of Performance may not be used to establish a 'before' condition.

Appendix C includes a sample analysis of before and after tests.

5.1 Individual Test Analysis - Circular Measurements

The reduction of raw data to a usable form must follow prescribed rules in order to ensure consistent and impartial analysis. Included in the analysis is an operator error value, designed to quantify the skill of the operators and the confidence level of the test data.

1. Calculate the average of all meter readings at each test point ($tpave_i$).

2. Calculate the average of all test points (avge).

3. Calculate the operator error values for multi-operator tests.

    a) Calculate the test average for each meter (avr_j).
    b) Calculate the calibration factor for each meter: $fac_j = avge/avr_j$.
    c) Disregard all unacceptable test points (labelled as BAD) for the remaining calculations.
    d) Calculate the ideal value for each meter at each test point:
    $ideal_{ij} = tpave_i/fac_j$.
    Example: If $fac_{meter\ b}$=1.05, then each meter b reading should ideally be 5% above each test point average ($tpave_i$).
    e) Calculate the standard deviation (sd_j) and maximum positive and negative deviations ($dpos_j$ and $dneg_j$) for each meter for non-BAD test points.

$$temp_{ij} = 100 \times \frac{x_{ij} - ideal_{ij}}{tpave_i}$$

$$sd_j = \sqrt{\sum \frac{temp_{ij}^2}{(n - 1)}}$$

$dpos_j$ = max positive $temp_{ij}$
$dneg_j$ = max negative $temp_{ij}$

sd_j should be less than 3, and preferably less than 2. Values above 3 indicate significant deviations in that meter relative to the other meter(s). This would imply that some of the test point values are inaccurate.

$dpos_j$ and $dneg_j$ show the largest magnitude of variation from the ideal value, and give an indication of the intrinsic level of inaccuracy in the test.

4. Scale all test point averages to the test radius.

   The scaling algorithms can be found in Reference #12 and Appendix D. The algorithms require the frequency, ground conductivity and relative dielectric constant of the ground (see Table 3 or the appropriate table in Reference Data for Radio Engineers).

5. Calculate the final test average using values from Step 4 (testavge).

Table 3 Relative Dielectric Constants of Ground

Terrain	Relative Dielectric Constant
Water	80
Rich farm land, low hills	15
Pastoral land, forestation and medium hills	13
Marshy, forested flat land	12
Dry, sandy, flat, coastal land Rocky land, steep hills	10
Mountainous Cities, residential areas	5
Cities, industrial areas	3

5.2 <u>Individual Test Analysis - Ratio Measurements</u>

The reduction of raw data to a usable form must follow prescribed rules in order to ensure consistent and impartial analysis. Included in the analysis is an operator error value, designed to quantify the skill of the operators and the confidence level of the test data.

Repeat steps 1-3 for each of the directional and omnidirectional measurements.

1. Calculate the average of all meter readings at each test point ($tpave_i$).

2. Calculate the average of all test points (avge).

3. Calculate the operator error values for tests where more than one operator was taking measurements. The operator error value represents a crude confidence level we can apply to each operator and to the test as a whole. Experience has shown that this value can be kept to a minimum by carefully following the guidelines of Section 4.2.

   a) Calculate the test average for each meter (avr_j).
   b) Calculate the calibration factor for each meter: $fac_j = avge/avr_j$.
   c) Disregard all test points labelled as BAD for the remainder of the operator error calculations.
   d) Calculate the ideal value for each meter at each test point:
      $ideal_{ij} = tpave_i/fac_j$.
      Example: If $fac_{meter\ b}$=1.05, then each meter b reading should ideally be 5% above each test point average ($tpave_i$).
   e) Calculate the standard deviation (sd_j) and maximum positive and negative variations ($dpos_j$ and $dneg_j$) for each meter for non-BAD test points.
      $dpos_j$ = max positive $temp_{ij}$
      $dneg_j$ = max negative $temp_{ij}$

   sd_j should be less than 3, and preferably less than 2. Values above 3

$$temp_{ij} = 100 \times \frac{x_{ij} - ideal_{ij}}{tpave_i}$$

$$sd_j = \sqrt{\sum \frac{temp_{ij}^2}{(n - 1)}}$$

indicate significant deviations in that meter relative to the other meter(s). This would imply that some of the test point values are inaccurate and perhaps invalid.

$dpos_j$ and $dneg_j$ show the largest magnitude of variation from the ideal value, and give an indication of the intrinsic level of inaccuracy of a particular test.

4. For each test point, calculate the ratio ($ratio_i$) of the directional average value ($tpave_i$: directional test) to the omnidirectional average value ($tpave_i$: omnidirectional test). These ratios give a normalized pattern.

5.3 Signal Fluctuation Analysis

The measured signal strength from a radio station varies surprisingly from day-to-day. This could be due to changes in antenna parameters, changes in ground conductivity, nearby construction, interference/noise, and operator error.

Signal fluctuations analysis requires that two similar tests be taken in quick succession. This minimizes long term effects, such as changes in ground conductivity and the presence of new structures. For ratio tests, the ratio of directional to omnidirectional measurements at each test point is used.

The following steps are used to arrive at the signal fluctuation value.

1. Determine the absolute value of the difference between the two readings at each test point as a percentage of the first test.

$$fluct_i = 100 \left| \frac{field_{i,first} - field_{i,second}}{field_{i,first}} \right|$$

2. Calculate the upper decile cutoff (F_{signal}). 10% of the test points have differences that are greater than this, and 90% have differences that are less.

3. If $F_{signal} < 10\%$ then $F_{signal} = 10\%$. This minimum value allows for typical meter accuracy and operator error.

Test-to-test analysis tends to focus attention on those test points with the greatest difference between the two measurements. The upper decile value represents these high fluctuations. In fact, if we analyze the same two tests used to quantify F_{signal}, 10% of the test points would have differences larger than typical signal fluctuations.

5.4 Seasonal Fluctuation Analysis

The received signal from a radio station in summer is usually quite different from that received in winter. This is mainly due to ground conductivity differences. Seasonal fluctuations can be quantified only if two before-construction or two after-construction tests were taken in opposite ground conductivity conditions. Where a choice of tests is present, use the tests with the largest difference in final test average. For ratio tests, the ratio of directional to omnidirectional measurements at each test point is used.

The following steps are necessary to arrive at the seasonal fluctuation value.

1. Determine the absolute value of the difference between the two readings at each test point as a percentage of the first test.

$$seas_i = 100 \left| \frac{field_{i,first} - field_{i,second}}{field_{i,first}} \right|$$

2. Calculate the upper decile cutoff (F_{season}). 10% of the test points have differences that are greater than this, and 90% have differences that are less.

3. If $F_{season} < 10\%$ then $F_{season} = 10\%$. This minimum value allows for typical meter accuracy and operator error.

Test-to-test analysis tends to focus attention on those test points with the greatest difference in measurements. The upper decile value represents these high fluctuations. In fact, if we analyze the same two tests used to quantify F_{season}, 10% of the test points would have differences larger than typical seasonal fluctuations.

5.5 Before vs. After Analysis - Circular Measurements

An 'after construction' circular measurement test is compared to a 'before construction' circular measurement to determine the effect on the pattern of the presence of the new reradiator. In order to discount ground conductivity changes, the before and after tests should be chosen to have the closest final test average (testavge). Variations between the two tests will be due to the reradiator in question, other reradiators, normal signal fluctuation, seasonal signal fluctuation, and operator error. The effect of the reradiator in question will be estimated by taking into account the other factors where possible.

The following are the analytical steps that will roughly indicate the effect of the reradiators.

1. To best account for ground conductivity changes, the after-construction measurements are scaled to the before-construction measurements with the closest final test average.

$$factor = \frac{testavge_{before}}{testavge_{after}}$$

$$newfield_i = field_{i,after} \times factor$$

2. Calculate the pattern deviation value (Dev) between the before-construction test and the scaled after-construction test as a percentage of the before-construction value.

Note that 0.1 mV/m is subtracted from the pattern difference to allow for an increase in inaccuracy for low level signals. These inaccuracies can arise from ambient noise, skywave, signals from co-channel stations and difficulty in measuring low level signals.

a) For each test point

$$\mathrm{Diff}_i = \mathrm{ABS}(\mathrm{field}_{i,before} - \mathrm{newfield}_i)$$

$$\text{if } \mathrm{Diff}_i \geq 0.1 \text{ mV/m then } \mathrm{Diff}_i = \mathrm{Diff}_i - 0.1 \text{ mV/m}$$

$$\mathrm{Pdev}_i = 100\ \mathrm{Diff}_i/\mathrm{field}_{i,before}$$

b) Calculate the upper decile cutoff (Dev) of the Pdev_i values. 10% of the test points have a Pdev_i greater than this, and 90% have a Pdev_i less than this.

3. The pattern deviation value should now be compared with the signal fluctuation values to determine if the test represents a problem.

   If Dev $\leq F_{signal}$ then the reradiators are minimally detrimental. The analysis stops.
   If Dev $\leq F_{season}$ then the reradiators are marginally detrimental.
   Otherwise, the reradiators can be considered to be noticeably detrimental.

4. The theoretical pattern and all protections to other stations should be scaled out to the test radius using the prevailing ground conductivity of the before test (see Reference #12 or the BASIC program listed in Appendix D). A graph should now be made with the theoretical pattern and protections, the measured before values, and the scaled measured after values. All test points where the values concern either of the parties should be listed.

5. For each test point of concern, determine the extent of reradiation. As some test points are more sensitive to changes in antenna parameters than others, the test point difference, Pdev_i from step 2a, should be compared to the overall test fluctuation values, F_{signal} and F_{season}, as well as the corresponding individual test point fluctuation values, fluct_i and seas_i (Sections 5.3 and 5.4).

   If $\mathrm{Pdev}_i \leq F_{signal}$ or $\mathrm{Pdev}_i \leq \mathrm{fluct}_i$, then this test point is minimally affected.
   If $\mathrm{Pdev}_i \leq F_{season}$ or $\mathrm{Pdev}_i \leq \mathrm{seas}_i$, then this test point is marginally affected.
   Otherwise, this test point can be considered to be noticeably affected.

6. Measurement errors may look like reradiation. However, reradiation is generally clumped in arcs, while measurement errors will be randomly located. If the test points indicating non-minimal effects are spaced more than 15° apart, then measurement error may be the cause of the variations.

5.6 Before vs. After Analysis - Ratio Measurements

An 'after construction' ratio measurement test is compared to a 'before construction' ratio measurement test to determine the effect on the pattern of the presence of the new reradiator. In order to discount ground conductivity changes, the before and after tests should be chosen to have the closest final test average (testavge). Variations between the two tests will be due to the reradiator in question, other reradiators, normal signal fluctuation, seasonal signal fluctuation, and operator error. The effect of the reradiator in question will be estimated by taking into account the other factors where possible.

The following are the analytical steps that will roughly indicate the effect of the reradiators.

1. Calculate the pattern deviation value (Dev) between the before-construction test and the after-construction test as a percentage of the before-construction value.

   Note that 1% is subtracted from the pattern ratio difference to allow for an increase in inaccuracy for low level signals. These inaccuracies can arise from ambient noise, skywave, signals from co-channel stations and difficulty in measuring low level signals.

   a) For each test point

   $$\mathrm{Diff}_i = \mathrm{ABS}(\mathrm{ratio}_{i,\mathrm{before}} - \mathrm{ratio}_{i,\mathrm{after}})$$
   $$\text{if } \mathrm{Diff}_i \geq 0.01 \text{ then } \mathrm{Diff}_i = \mathrm{Diff}_i - 0.01$$
   $$\mathrm{Pdev}_i = 100\ \mathrm{Diff}_i/\mathrm{field}_{i,\mathrm{before}}$$

   b) Calculate the upper decile cutoff (Dev). 10% of the test points have a Pdev_i greater than this, and 90% have a Pdev_i less than this.

2. The pattern deviation value should now be compared with the signal fluctuation values to determine if the test represents a problem.

   If Dev $\leq F_{signal}$ then the reradiators are minimally detrimental. The analysis stops.
   If Dev $\leq F_{season}$ then the reradiators are marginally detrimental.
   Otherwise, the reradiators can be considered to be noticeably detrimental.

3. All test points where the change in ratios is of concern to either party should be listed. This should take into account protections and coverage.

4. For each test point of concern, determine the extent of reradiation. As some test points are more sensitive to changes in antenna parameters than others, the test point ratio difference, Pdev_i from step 2a, should be compared to the overall test fluctuation values, F_{signal} and F_{season}, as well as the appropriate individual test point fluctuation values, fluct_i and seas_i (Sections 5.3 and 5.4).

   If $\mathrm{Pdev}_i \leq F_{signal}$ or $\mathrm{Pdev}_i \leq \mathrm{fluct}_i$, then this test point is minimally affected.
   If $\mathrm{Pdev}_i \leq F_{season}$ or $\mathrm{Pdev}_i \leq \mathrm{seas}_i$, then this test point is marginally affected.
   Otherwise, this test point can be considered to be noticeably affected.

5. Measurement errors may look like reradiation. However, reradiation is generally clumped in arcs, while measurement errors will be randomly located. If the test points indicating non-minimal effects are spaced more than 15° apart, then measurement error may be the cause of the variations.

5.7 'After Construction Only' Analysis - Circular Measurements

The absence of proper before-construction measurements seriously undermines the confidence level of any analysis. The pattern cannot be considered to have been perfect before construction of the potential reradiators, and the deviation from perfection is unknown. As a result, computer prediction programs must be used to indicate expected variations.

The following are the analytical steps that will roughly indicate the effect of the reradiators.

1. The protections and the theoretical pattern should be scaled out to the test radius using the measured ground conductivities of the low-conductivity and high-

conductivity tests. This can be done by taking the unattenuated theoretical field strengths at 1 km or 1 mile, and using the algorithms in Reference #12, or the BASIC computer program of Appendix D, or suitable graphs which can be found in Reference #14. If two conductivities are not available, or are not significantly different, then use values that would best approximate the conductivity extremes for that area.

2. All measured 'after construction' patterns should be plotted on the same graph as the protections and the theoretical pattern. All test points where the values concern either of the parties should be listed.

3. Calculate the pattern deviation value (Dev_{high}) between the high ground conductivity test and the high ground conductivity theoretical pattern as a percentage of the theoretical value. If two high-ground-conductivity tests took place in quick succession, then use the average of the two measurements as $field_{i,high}$. If the test point occurs in a direction with a protection to another station, then use the high-conductivity protection value as $theory_{i,high}$.

   Note that 1% is subtracted from the difference at each test point to allow for an increase in inaccuracy for low level signals. These inaccuracies can arise from ambient noise, skywave, signals from co-channel stations and difficulty in measuring low level signals.

   a) For each test point

   $$Diff_{i,high} = ABS(field_{i,high} - theory_{i,high})$$
   $$\text{if } Diff_{i,high} \geq 0.01 \text{ then } Diff_{i,high} = Diff_{i,high} - 0.01$$
   $$Pdev_{i,high} = 100\ Diff_{i,high}/field_{i,high}$$

   b) Calculate the upper decile cutoff (Dev_{high}). 10% of the test points have a $Pdev_{i,high}$ greater than this, and 90% have a $Pdev_{i,high}$ less than this.

4. Calculate the pattern deviation value (Dev_{low}) between the low ground conductivity test and the low ground conductivity theoretical pattern as a percentage of the theoretical value. If two low-ground-conductivity tests took place in quick succession, then use the average of the two measurements as $field_{i,low}$. If the test point occurs in a direction with a protection to another station, then use the low-conductivity protection value as $theory_{i,low}$.

   Note that 1% is subtracted from the difference at each test point to allow for an increase in inaccuracy for low level signals. These inaccuracies can arise from ambient noise, skywave, signals from co-channel stations and difficulty in measuring low level signals.

   a) For each test point

   $$Diff_{i,low} = ABS(field_{i,low} - theory_{i,low})$$
   $$\text{if } Diff_{i,low} \geq 0.01 \text{ then } Diff_{i,low} = Diff_{i,low} - 0.01$$
   $$Pdev_{i,low} = 100\ Diff_{i,low}/field_{i,low}$$

   b) Calculate the upper decile cutoff (Dev_{low}). 10% of the test points have a $Pdev_{i,low}$ greater than this, and 90% have a $Pdev_{i,low}$ less than this.

5. The pattern deviation value should now be compared with the signal fluctuation values to determine if the test could represent a problem.

If $Dev_{high} \le F_{signal}$ and $Dev_{low} \le F_{signal}$ then the reradiators are minimally detrimental. The analysis stops.
If $Dev_{high} \le F_{season}$ and $Dev_{low} \le F_{season}$ then the reradiators are minimally detrimental. The analysis stops.
Otherwise, the reradiators may be noticeably detrimental and the analysis continues.

6. Some test points are more sensitive to changes in antenna parameters than others. Therefore, the test point pattern deviation values, $Pdev_{i,high}$ from step 3 and $Pdev_{i,low}$ from step 4, should be compared to the signal fluctuation values, F_{signal} and F_{season} from Sections 5.3 and 5.4, as well as the appropriate individual test point signal fluctuation values, $fluct_i$ and $seas_i$. Determine the possible effect of reradiation at each test point of concern, as follows:

   If $Pdev_{i,high} \le F_{signal}$ or $Pdev_{i,high} \le fluct_i$ then the test point is minimally affected for high ground conductivities.
   If $Pdev_{i,low} \le F_{signal}$ or $Pdev_{i,low} \le fluct_i$ then the test point is minimally affected for low ground conductivities.
   If the test point is minimally affected for both high and low ground conductivities, then the test point is minimally affected.

   If $Pdev_{i,high} \le F_{season}$ or $Pdev_{i,high} \le seas_i$ then the test point is minimally affected for high ground conductivities.
   If $Pdev_{i,low} \le F_{season}$ or $Pdev_{i,low} \le seas_i$ then the test point is minimally affected for low ground conductivities.
   If the test point is minimally affected for both high and low ground conductivities, then the test point is minimally affected.

   Otherwise, there is still the possibility that the test point is noticeably affected by reradiation from the structure in question.

7. One of the reradiation prediction programs should be run, simulating before and after cases. *The before case **must** include all existing buildings and power lines in the nearby area (other than the power line being studied). The exact locations of existing power line towers should be used.* The after case will include the power line being studied.

   The two computer runs and the theoretical pattern should then be compared, as follows:

   a) Determine all directions where the predicted after construction value is farther from the theortical value than the predicted before construction value is.
   b) For each direction found in a) above, consider only those directions where the difference between the after and before values as a percentage of the before value is greater than F_{signal}.
   c) The remaining directions of concern should be cross-referenced with any test points which may be noticeably affected. Those directions where both the computer runs and the measured values indicate a problem, can be considered to have been affected to some extent by the reradiators in question.

8. Measurement errors may look like reradiation. However, reradiation is generally clumped in arcs, while measurement errors will be randomly located. If the test points indicating noticeable effects are spaced more than 15° apart, then measurement error may be the cause of the variations.

5.8 'After Construction Only' Analysis - Ratio Measurements

The absence of proper before-construction measurements seriously undermines the confidence level of any analysis. The pattern cannot be considered to have been perfect before construction of the potential reradiators, and the deviation from perfection is unknown. Computer prediction programs must be used to indicate expected variations.

The following are the steps that will roughly indicate the effect of the reradiators.

1. The protections and the unattenuated theoretical pattern should be plotted at 1 km or 1 mile.

2. All measured 'after construction' ratios should be plotted on the same graph as the protections and the theoretical pattern. The ratios should be normalized to have the same RMS value as the theoretical pattern RMS.

$$RMS_{ratio} = \sqrt{\frac{\sum_{i=1}^{n} ratio_i^2}{n}}$$

$$scaled_i = ratio_i \frac{RMS_{theory}}{RMS_{ratio}}$$

   All test points where the ratios concern either of the parties should be listed.

3. Calculate the pattern deviation value (Dev) between the measured ratio and the theoretical pattern as a percentage of the theoretical value. If two or more ratio tests took place in quick succession, then use the average of the ratios as $ratio_i$. If the test point occurs in a direction with a protection to another station, then use the protection value as $theory_i$.

   Note that 1% is subtracted from the difference at each test point to allow for an increase in inaccuracy for low level signals. These inaccuracies can arise from ambient noise, skywave, signals from co-channel stations and difficulty in measuring low level signals.

   a) For each test point
      $Diff_i = ABS(scaled_i - theory_i)$
      if $Diff_i \geq 0.01$ then $Diff_i = Diff_i - 0.01$
      $Pdev_i = 100\ Diff_i/scaled_i$

   b) Calculate the upper decile cutoff (Dev). 10% of the test points have a $Pdev_i$ greater than this, and 90% have a $Pdev_i$ less than this.

4. The pattern deviation value should now be compared with the signal fluctuation values to determine if the test could represent a problem.

If Dev $\leq F_{signal}$ or Dev $\leq F_{season}$ then the reradiators are minimally detrimental. The analysis stops.
Otherwise, the reradiators may be noticeably detrimental and the analysis continues.

5. Some test points are more sensitive to changes in antenna parameters than others. Therefore, the test point pattern deviation values, $Pdev_i$ from step 3 should be compared to the signal fluctuation values, F_{signal} and F_{season} from Sections 5.3 and 5.4, as well as the appropriate individual test point signal fluctuation values, $fluct_i$ and $seas_i$. Determine the possible effect of reradiation at each test point of concern, as follows:

   If $Pdev_i \leq F_{signal}$ or $Pdev_i \leq fluct_i$ then the test point is minimally affected.
   If $Pdev_i \leq F_{season}$ or $Pdev_i \leq seas_i$ then the test point is minimally affected.
   Otherwise, there is still the possibility that the test point is noticeably affected by reradiation from the structure in question.

6. One of the reradiation prediction programs should be run, simulating before and after cases. *The before case* ***must*** *include all existing buildings and power lines in the nearby area (other than the power line being studied). The exact locations of existing power line towers should be used.* The after case will include the power line being studied.

   The two computer runs and the theoretical pattern should then be compared, as follows:

   a) Determine all directions where the predicted after construction value is farther from the theoretical value than the predicted before construction value is.
   b) For each direction found in a) above, consider only those directions where the difference between the after and before values as a percentage of the before value is greater than F_{signal}.
   c) The remaining directions of concern should be cross-referenced with any test points which may be noticeably affected. Those directions where both the computer runs and the measured ratios indicate a problem, can be considered to have been affected to some extent by the reradiators in question.

7. Measurement errors may look like reradiation. However, reradiation is generally clumped in arcs, while measurement errors will be randomly located. If the test points indicating noticeable effects are spaced more than 15° apart, then measurement error may be the cause of the variations.

6. STRUCTURE RERADIATION MEASUREMENTS

Structure reradiation measurements refer to any method of quantifying the amount of signal reradiating from a structure. This includes base current measurements, structure field strength readings and magnetic-field probes. Scale model measurements can assist the measurement process. Any method that can give relative or absolute indications of the signal strength emanating from a structure can be useful in determining problem structures, and in determining the effectiveness of remedial measures.

6.1 Base Current Measurements

Current measurements can be used to determine the RF current flowing in structures. For structures near a quarter wavelength tall the current at the base of the structure is a quick and easy indicator of the overall current in the structure[7,10]. For structures close to a half wavelength tall, the technique does not work as the base current will be close to zero. Predicting the far-field effect from the base current alone is difficult, as the additive effect of all of the reradiators is dependent on knowing the relative phase of each reradiator current.

Base current measurements can be taken using toroidal current transformers. Two such devices should be used, with one set up as a phase reference. Measurements can be made on all four legs of a transmission tower. The current can then be summed vectorially to determine the total tower base current.

Structures with the highest base current will reradiate the most. As a general rule these structures would be the best candidates for remedial measures. However, this is not always the case, as a lower base current structure closer to a sensitive portion of the pattern may disturb the pattern more.

6.2 Structure Field Strength Readings

A field strength meter can be used to provide a relative measure of the reradiated field from a structure. Comparisons of radiating fields from different structures, and of the field of one structure before and after detuning are possible.

To be effective, only reradiation from the structure in question must be measured. For isolated structures this is possible by keeping the source signal in the null of the meter. The readings can then be taken up to 400 m away from the structure. Structures must be less than $\lambda/2$ in height or else portions of the tower current will cancel each other in the far field, but not in the near field.

It is impossible to use the above technique where multiple sources can interfere with the measurements, such as power lines and antenna arrays. In these cases, the field strength meter is only useful when very close to the base of the structure. (The structure must be less than $\lambda/2$ tall). By using a constant distance of 5 m or less, comparisons of relative field strength can be made between similar structures, such as individual power line towers. NOTE: This technique does not work with structures detuned with a stub. The stub may cause an increase in circulating current which cancels itself in the far field, and yet stronly affects nearby field strength readings.

6.3 Scale Model Measurements

Scale model measurements offer distinct advantages over full scale measurements: They are quicker to do, individual structures can be studied in isolation, and remedial measures can be tuned exactly. However, they cannot easily include losses due to the ground or building materials; they cannot include all the details of the structure in question (600:1 models would have to use about 0.022 mm diameter wire); and in simplifying they tend to misrepresent some aspects, such as skywire sag or tower footing impedance.

Scale models are good at indicating which structures are the most likely to radiate, and which remedial measures are most likely to work. However, due to their simplicity and isolation, scale model measurements can not be used to prove that a reradiation problem exists.

7. REMEDIAL MEASURES OR ALTERNATIVES

Remedial measures are those devices used or actions taken to reduce or minimize the pattern distortion. This may include attaching physical detuning devices to the reradiating structures, altering the structure, or altering the positions of the structures.

Effective remedial measures should be easy to tune, be effective over a bandwidth of 20 kHz, and be acceptable to the designers and users of the structure. Tradeoffs between the cost and effectiveness of different measures makes the final selection very important.

It should be noted when designing or specifying remedial measures that the resonant height of a power-line tower has been measured at close to 0.2λ, and not 0.25λ [7]. This is most likely because of the top-loading effect of numerous cross-arms parallel to the ground.

7.1 Power-Line Tower Skywire Insulation

Insulation of the skywires (overhead ground wires) from a power-line tower is the cheapest remedial measure currently available. Adequate lightning protection can often be maintained by connecting every second or third tower to the skywire(s). Towers that are shorter than 0.2λ are not resonant on their own, and skywire insulation should effectively break up any resonant tower-to-tower loops. Unfortunately, for towers close to 0.2λ tall, insulation of the skywire could increase the overall reradiation by creating a resonant stand-alone structure. The possibility of creating resonant double-span loops should also be considered.

An excellent study of skywire insulation was performed on a station in Edmonton, Canada[8]. Field strengths, tower base current and numerical predictions were involved. Resonant loops were identified on the computer and verified to some extent with actual base current measurements. The skywire was then insulated from one tower in each of the resonant loops and the tower base current were measured again. The reduction in base current indicated that a significant reduction in reradiation could be expected. Follow-up field strength measurements verified this.

7.2 Power-Line Tower Detuning Stubs

Detuning stubs may be attached to power-line towers to alter its effectiveness as an antenna[5,7,10]. A stub detuner alters the induced current distribution in the tower. By using a quarter wavelength (λ/4) stub, the far field radiation can be minimized. The stubs consist of wires or bundles of wires with one end connected directly to the top of the tower and the other end connected through a variable impedance. The variable impedance is tuned to electrically create a λ/4 stub. For stubs less than λ/4 tall, capacitive impedance is required, while longer stubs require inductance.

There are two important features of tower stubs that affect the cost and performance. First, the bandwidth of the stub is affected by the amount of capacitance or inductance used in the stub tuning circuit. The widest bandwidth is for a stub exactly a quarter wavelength long requiring no additional reactance at all. For towers over λ/4 tall, reactive components can be avoided by limiting the stub to λ/4. Shorter towers will still require capacitance.

The second factor is the separation between the stub and the tower. The farther out the stub, the better the shielding and the more effective the detuning[5]. For the upper portion of the tower, the conductors may limit the separation. For the lower part of the tower, this restriction will not apply.

Figures 1, 2 and 3 show three stub designs with increasing effectiveness. The stubs are shown on one leg only for ease of viewing. Actual stubs would probably be installed on all four legs of the tower. Some amount of periodic maintenance would be required.

The simplest design is the straight stub (Figure 1) involving a wire similiar to the overhead ground wire strung down each tower leg. It is attached to the tower at the top, and insulated with stand-off insulators for the rest of the structure. The stub is terminated with the tuning circuit at the bottom. Attached to two legs, this stub design has achieved 15 dB reduction in base current[7]. Attached to all four legs the base current reduction became about 20 dB.

Better performance can be achieved with the use of the "Elbow" stub (Figure 2) which is pulled out from the tower below the bent line[7]. A rope or other nonconducting device can be used to hold the stub out. It is terminated with a tuning circuit at the bottom and has achieved 27 dB reduction in base current.

The best performance can be achieved with the "Double-Elbow" stub (Figure 3). Two elbow are pulled out from each corner of the tower at right angles to each other. Both are then terminated in separate tuning circuits at the bottom. This allows for two frequency detuning. Tests have shown up to 32 dB reduction in base current at one frequency and 26 dB at the second frequency[7].

7.3 Power-Line Skywire Stubs

There is a certain amount of controversy concerning the usefulness and appropriateness of skywire stubs. Numerical computations and scale model studies have predicted these stubs to be excellent detuners[8], while full scale studies have shown them to have serious problems[7]. Advantages include wide bandwidth effect and universal design irrespective of tower type. Disadvantages include installation and alteration difficulties, power system security problems and tuning inaccuracy.

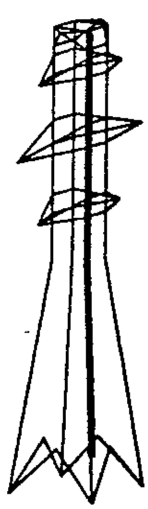

Figure 1 Straight Stub on one tower leg

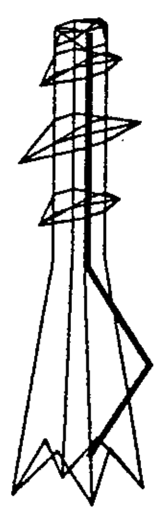

Figure 2 Elbow Stub on one one tower leg

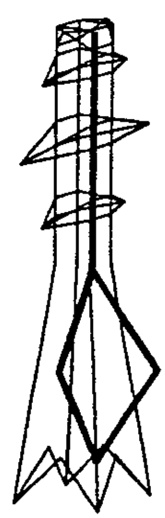

Figure 3 Double-Elbow Stub on one tower leg

Two types of skywire stubs have been investigated. The $\lambda/4$ skywire stub involves suspending a $\lambda/4$ long wire 0.5 m under the skywire (using insulated standoffs) and connecting it at a point of current minimum. (The skywire current must have already been measured or calculated.) Attached to both sides of a tower, a 32 dB reduction in tower base current was achieved at a frequency 30 kHz from the target frequency[7]. The target frequency current was reduced 13 dB.

The 'broken' skywire stub requires two skywires. Insulators are used to break up one skywire at two points, leaving an isolated section between them. One end of this section is connected to the other skywire using a jumper. The total length of the jumper plus isolated section should be $\lambda/4$. The point of connection is not critical. Attached to both sides of a tower, the current was reduced 11 dB at 50 kHz from the target frequency, and 9 dB at the target frequency[7].

7.4 Alternatives

Relocation of structures is an active remedial measure available to either party. This could include repositioning individual towers to avoid resonant spans, rerouting the proposed power-line to avoid the area, or relocating the AM antenna array. These methods could be costly.

Selection of tower locations involves many factors, including agricultural laws, location of roads and creeks, maximum tower heights, allowable tensions, ground conditions, overall project budgets, and even public visibility. Utilities have very little freedom in repositioning towers, even in the planning stage.

An expensive alternative would be for the radio station to apply for a different frequency or pattern.

A rather exotic alternative would be to base insulate the tower. This can be done by inserting non-conducting spacers between the splice plate and the tower legs, and non-conducting sleeves over the bolts. As high RF voltages may appear between the ground and the tower, the site would need to be adequately fenced and labelled.

As a last resort, all parties could agree to accept the consequences of the distortion, subject to the regulating agency agreeing to the form of the altered pattern.

8. REFERENCES

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[2] Canadian Department of Communication Working Group on Reradiation Problems in AM Broadcasting, "Final Report", Final Report of the Working Group as written by Tilston, M.A., July 12, 1985.

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[4] Royer, G.M., "The Effects of Reradiation from High-Rise Buildings and Towers upon the Antenna Patterns for AM Broadcast Arrays", Proceedings of the IEEE International Symposium on Electromagnetic Compatibility, Boulder, Colorado, August 18-20, 1981, pp. 372-378.

[5] Tilston, M.A. and Balmain, K.G., "Medium Frequency Reradiation from a Steel Tower Power Line with and without a Detuner", IEEE Transactions on Broadcasting, Vol. BC-30, No. 1, March, pp. 17-26.

[6] Trueman, C.W., Kubina, S.J., Madge, R.C. and Jones, D.E., "Comparison of Computed RF Current Flow on a Power Line with Full Scale Measurements", IEEE Transactions on Broadcasting, Vol. BC- 30, No.3, September, pp. 97-107.

[7] Jones, D.E. and Madge, R.C., "Measurement of Reradiation of Broadcast Signals by Power Lines", CEA Report No. 023-T-216, March, 1983.

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[11] Addendum No. 2 to Document No. 12-E, Regional Broadcasting Conference, International Telecommunications Union, Buenos Aires, 1980.

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[13] Agreement between the Government of Canada and the Government of the United States of America relating to the AM Broadcasting Service in the Medium Frequency Band, Ottawa, 1984.

APPENDIX A. RERADIATION PREDICTION COMPUTER PROGRAMS

The following is a list of some of the computer programs that can be used for prediction of reradiation. Other programs may be available or are being developed that can also be used. This is not intended to be an endorsement of any particular program.

NEC

Mainframe		Concordia Univ. Loyola Campus 7141 Sherbrooke St.W. Montreal, Quebec H4B 1R6
	attn:	Dr. C.W. Trueman Dr. S.J. Kubina

AMPL

Mainframe PC		University of Toronto Dept. of Elec. Eng. Toronto, Ontario M5S 1A4
	attn:	M. Tilston

RERADPC

PC		Ontario Hydro Research Division 800 Kipling Avenue Toronto, Ontario M8Z 5S4
	attn:	R.C. Madge

APPENDIX B. RERADIATION SURVEY EXAMPLE

The reradiation survey from Section 3.2 and Table 2 will be carried out to determine if this sample situation could be a problem. A station has a directional radiation pattern and a frequency of 680 kHz. The minimum pattern tolerance is 15 mV/m at 1 km, (minimum difference between the theoretical pattern and the upper or lower pattern limitation). There are a few structures in the area, including a building and a power line.

The building is 40 m high and located 5 km from the array. The unattenuated 1 km field in that direction is 1000 mV/m. A power line with towers of 35 m and loops of 420 m (2 towers plus span plus reflection in ground) comes within 3.8 km. The unattenuated 1 km field in that direction is 1540 mV/m.

(a) Building

$$\lambda = \frac{3 \times 10^8 \; m/sec}{680{,}000 \; Hz} = 440.9m$$

$$r = \frac{Tol_{min} \times Dist}{Field \times \lambda}$$

$$= \frac{15 \; mV/m \times 5000 \; m}{1000 \; mV/m \times 440.9 \; m} = 0.1701$$

Since $0.1 \leq r \leq 0.2$:

From Table 2 we get Max. structure height = r λ = 75 m.
The building is acceptable.

(b) Power Line Towers

$$r = \frac{15 \; mV/m \times 3800 \; m}{1540 \; mV/m \times 440.9 \; m} = 0.0839$$

Since $0.02 \leq r < 0.1$:

From Table 2 we get Max. tower height = (0.025 + 0.75r) λ = 38.8 m.
The towers are acceptable.

(c) Power Line Loops

r = .0839 (from above)

Since $0.02 \leq r < 0.1$:

From Table 2 we get Max. loop length = (0.76 + 2r) λ = 409 m

As our power line loops are typically 420 m we may have a problem. The situation should now be analyzed using one of the accepted computer programs to determine if a field study needs to be performed.

APPENDIX C. BEFORE vs AFTER - CIRCULAR MEASUREMENT EXAMPLE

This appendix will analyze a simplified reradiation problem. Three before tests and one after test are included. Although real tests would include 80 or more test points, this example will consider only 10 test points to keep the sample analysis short. Table C-1 contains the raw data.

Frequency = 1 MHz   Test radius = 10 kilometres   Relative Dielectric Constant of Ground = 12

C.1 Individual Test Analysis Example - Circular Measurements

To keep this sample analysis to a reasonable length, we will analyse only Before Test 3. The following analysis refers to the procedures listed in Section 5.1.

1. Calculate the average of each test point (tpa_i).

$tpa_1 = (108 + 113)/2 = 110.5$ mV/m
$tpa_2 = (102 + 108)/2 = 105.0$
$tpa_3 = (94 + 102)/2 = 98.0$
$tpa_4 = (96 + 98)/2 = 97.0$
$tpa_5 = (80 + 81)/2 = 80.5$
$tpa_6 = (87 + 92)/2 = 89.5$
$tpa_7 = (97 + 111)/2 = 104.0$
$tpa_8 = (105 + 115)/2 = 110.0$
$tpa_9 = (122 + 133)/2 = 127.5$
$tpa_{10} = (132 + 140)/2 = 136.0$

Table C-I Raw Data for Appendix C Example

Test point	1	2	3	4	5	6	7	8	9	10
Dist (km)	11	10	9	10	10	10	10	10	10	10
Azimuth	2.5	5	10	15	20	25	30	35	40	45
Before Test 1							Ground Conductivity = 6 mS/m			
Code	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
Meter 'a'	100	90	85	86	75	82	94	100	110	120
Meter 'b'	104	96	89	87	78	84	99	106	115	128
Before Test 2							Ground Conductivity = 6 mS/m			
Code	OK	OK	OK	OK	OK	?	OK	OK	OK	BAD
Meter 'a'	103	94	92	85	76	85	98	106	120	127
Meter 'b'	114	98	97	91	77	90	104	109	126	133
Before Test 3							Ground Conductivity = 9 mS/m			
Code	OK	OK	OK	OK	?	OK	OK	OK	OK	BAD
Meter 'a'	108	102	94	96	80	87	97	105	122	132
Meter 'b'	113	108	102	98	81	92	111	115	133	140
After Test							Ground Conductivity = 7 mS/m			
Code	OK	OK	OK	OK	?	OK	OK	OK	OK	BAD
Meter 'a'	84	97	91	87	84	86	101	111	119	121
Meter 'b'	90	106	99	97	93	92	114	115	122	126

2. Calculate the average of all test points (avge).

avge = (110.5 + ... + 136)/10 = 105.8 mV/m

3. Calculate the operator error values (sd_j, $dpos_j$. $dneg_j$)

a) Calculate the overall test average for each meter (avr_j).

avr_a = (108 + ... + 132)/10 = 102.3 mV/m
avr_b = (113 + ... + 140)/10 = 109.3

b) Calculate the calibration factor for each meter (fac_j).

$fac_a = avge/avr_a$ = 105.8/102.3 = 1.034
fac_b = 105.8/109.3 = 0.968

c) Disregard unacceptable test point 10 for the rest of operator error calculations.

d) Calculate the ideal value for each test point for each meter.

ex. tp#1, meter 'a'

$ideal_{1a} = tpa_1/fac_a$ = 110.5/1.034 = 106.8

The other values are calculated in a similar fashion.

ideal$_{ij}$	**Meter a**	**Meter b**
Test point 1	106.8	114.2
2	101.5	108.5
3	94.8	101.2
4	93.8	100.2
5	77.8	83.2
6	86.5	92.5
7	100.6	107.4
8	106.4	113.6
9	123.3	131.7
10	BAD	BAD

e) Calculate the standard deviation (sd_j) and maximum positive and negative deviations ($dpos_j$, $dneg_j$) for all non-BAD test points.

$$temp_{ij} = 100 \frac{x_{ij} - ideal_{ij}}{tpave_i}$$

$$sd_j = \sqrt{\sum \frac{temp_{ij}^2}{(n - 1)}}$$

where n = # of non-BAD test points = 4

$dpos_j$ = max positive $temp_{ij}$
$dneg_j$ = max negative $temp_{ij}$

	sd %	dpos %	dneg %
Meter a	1.90	2.69	3.42
Meter b	1.90	3.42	2.69

The operator errors in this over-simplified example are acceptable, with the standard deviation under 2 and the maximum deviations under 5%.

4. Scale all test point averages to the test radius ($field_i$). In our example, the test radius is 10 km. Only test points 1 (11 km) and 3 (9 km) require calculations.

   The test point average and distance, test radius, ground conductivity and relative dielectric constant were all fed into the program listed in Appendix D.

   $field_1$ = 124.0 mV/m
   $field_2$ = 105.0
   $field_3$ = 85.6
   $field_4$ = 97.0
   $field_5$ = 80.5
   $field_6$ = 89.5
   $field_7$ = 104.0
   $field_8$ = 110.0
   $field_9$ = 127.5
   $field_{10}$ = 136.0

5. Calculate the final test average (testavge).

   testavge = (124.0 + ... + 136)/10
   = 105.9 mV/m

Steps 4 and 5 contain the essential information for a test-to-test comparison. This test is best compared to one where the final test average is very close to 105.9 mV/m, indicating similar ground conditions.

C.2 Typical Signal Fluctuation Example

For this example, Before Tests 1 and 2 will be used to determine the typical signal fluctuation, F_{signal}, as described in Section 5.3. The scaled test point averages used below are derived from the raw data given at the start of this appendix. The signal fluctuation analysis involves determining, at each test point, the absolute value of the difference between the two tests as a percentage of the first test.

	Before Test 1	Before Test 2	$Fluct_i$ %
TP 1	117.0	124.5	6.4
2	93.0	96.0	3.2
3	75.0	81.5	9.1
4	86.5	88.0	1.7
5	76.5	76.5	0.0

6	83.0	87.5	5.4
7	96.5	101.0	4.7
8	103.0	107.5	4.4
9	112.5	123.0	9.4
10	124.0	BAD	BAD

The next step is to calculate the upper decile cutoff value where 10% of the differences are greater than this value, and 90% are smaller. In our example of only 10 test points, this is best represented by the second largest difference: 9.1%.

Lastly, since the upper decile cutoff is less than 10%, then F_{signal} = 10%.

C.3 Seasonal Signal Fluctuation Example

Two tests representing opposite ground conditions are used to determine the seasonal signal fluctuation, F_{season}, as described in Section 5.4. This is determined by taking the two before tests or two after tests with the highest difference in final test averages. The final test averages used below are derived from the raw data given at the start of this appendix.

Final test averages Before Test 1: 96.7 mV/m
Before Test 2: 101.5
Before Test 3: 105.9
After Test : 102.0

The two tests to use are Before Tests 1 and 3. The seasonal signal fluctuation analysis involves determining, at each test point, the absolute value of the difference between the two test point averages as a percentage of the first test.

	Before Test 1	**Before Test 3**	**$Seas_i$ %**
TP 1	117.0	124.0	6.0
2	93.0	105.0	12.9
3	75.0	85.6	14.1
4	86.5	97.0	12.1
5	76.5	80.5	5.2
6	83.0	89.5	7.8
7	96.5	104.0	7.8
8	103.0	110.0	6.8
9	112.5	127.5	13.3
10	124.0	136.0	9.7

The next step is to calculate the upper decile cutoff value where 10% of the differences are greater than this value, and 90% are smaller. In our example of only 10 test points, this is best represented by the second largest difference: 13.3%.

Lastly, if the upper decile cutoff is less than 10%, then F_{season} = 10%. This proviso does not apply here.

C.4 Before vs After Analysis Example

The 'after construction' test will be compared to the 'before construction' test of closest final test average. From the final test averages listed in Section C.3, we see this is Before Test 2.

1. Scale After Test to Before Test 2.

   $\text{factor} = \text{testavge}_{before}/\text{testavge}_{after} = 101.5/102.0 = 0.995$

   $\text{newfield}_{i,after} = \text{field}_{i,after} \times \text{factor}$

	Before Test 2	After Test	Scaled After Test
TP 1	124.5	99.3	98.8
2	96.0	101.5	101.0
3	81.5	82.4	82.0
4	88.0	92.0	91.5
5	76.5	88.5	88.1
6	87.5	89.0	88.6
7	101.0	107.5	107.0
8	107.5	113.0	112.4
9	123.0	120.5	119.9
10	BAD	BAD	BAD

2. Calculate the pattern deviation value Dev. This is the absolute value of the difference between the two tests as a percentage of the first test.

   a) Calculate the difference at each test point.

$$\text{Diff}_i = |\text{field}_{i,before} - \text{newfield}_{i,after}|$$

$$\text{Diff}_i = \text{Diff}_i - 0.1 \text{ mV/m}$$
$$\textit{if } \text{Diff}_i < 0 \text{ then } \text{Diff}_i = 0$$

$$\text{Pdev}_i = 100 \times \frac{\text{Diff}_i}{\text{field}_{i,before}}$$

	Diff_i mV/m	Pdev_i %
TP 1	25.6	20.6
2	4.9	5.1
3	0.4	0.5
4	3.4	3.9
5	11.5	15.0
6	1.0	1.1
7	5.9	5.8
8	4.8	4.5
9	3.0	2.4
10	BAD	BAD

b) The upper decile cutoff value in this example would be represented by the second largest difference.

Therefore Dev = 15.0%.

3. Dev > F_{season}, so the reradiators are noticeably detrimental.

4. The theoretical pattern and all protections and coverages are scaled out the test radius according to the prevailing ground conductivity of the before test (see Reference #12 or Appendix D). These curves are shown in Figure C-1, along with the before and scaled-after test results. Let's assume that the participants identify directions towards test points 1, 2, 3, 5, 9 and 10 as directions of concern.

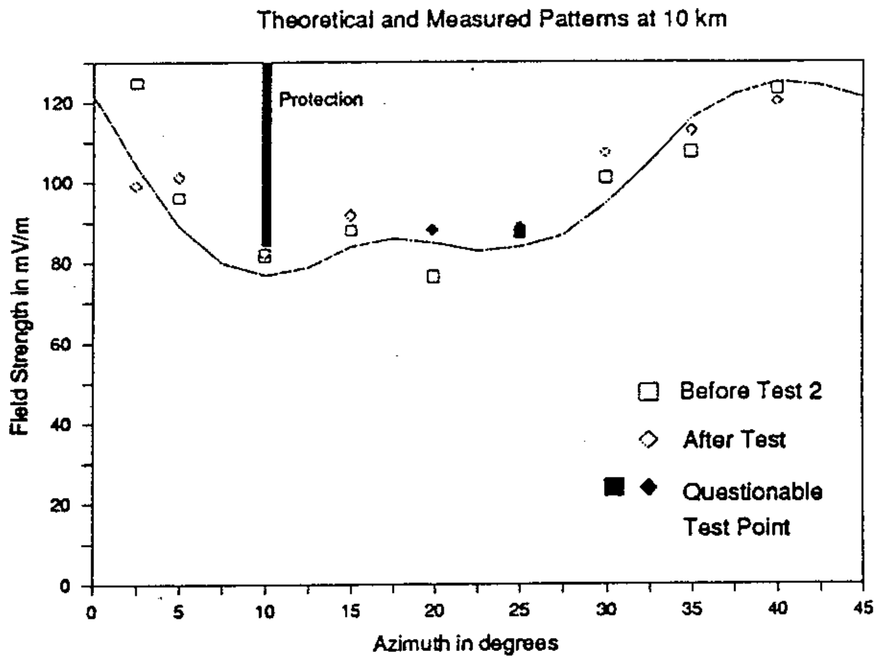

Figure C-1. Comparison of Theoretical and Measured Patterns for Appendix C Example

5. Each test point of concern is then to be analyzed according to its measured difference $Pdev_i$, and signal and seasonal fluctuation values. These have already been calculated in previous sections.

F_{signal} = 10%
F_{season} = 13.3%

	$Pdev_i$	$fluct_i$	$seas_i$
TP 1	20.6%	6.4%	6.0%
2	5.1	3.2	12.9
3	0.5	9.1	14.1
5	15.0	0.0	5.2
9	2.4	9.4	13.3
10	BAD	BAD	BAD

From the table of deviations, we see that

$Pdev_1 > F_{season}$ and $Pdev_1 > seas_1$, so TP 1 is noticeably affected by the reradiators.
$Pdev_2 \leq F_{signal}$, so TP 2 is minimally affected.
$Pdev_3 \leq F_{signal}$, so TP 3 is minimally affected.
$Pdev_5 > F_{season}$ and $Pdev_5 > seas_5$, so TP 5 is noticeably affected. However, as this was declared a questionable test point in the after test, there is still some question of its status.
$Pdev_9 < F_{signal}$, so TP 9 is minimally affected.
Test Point 10 was declared BAD in at least one of the tests, and so an analysis is not possible on this test point.

6. As a result of our analysis, Test Points 1 and 5 are found to be noticeably affected by the reradiators. It should be noted that Test Point 5 was found to be a questionable test point in the after test, indicating some problem with the measurement. As the neighboring test points 4 and 6 had much lower measured differences (3.9% and 1.1% respectively), the measured distortion at test point 5 may be in part due to the measurement problem. The status of test point 5 rests to a certain degree on the presence or absence of other problem test points in the immediate area.

   Test Point 1 shows a significantly higher difference than any other test points. The simplicity of our example does not allow us to fully study the situation properly. If this was the only noticeably affected test point out of 80 test points, we would be tempted to say that other causes (such as local construction near th[illegible] test point, operator error, antenna parameter changes, etc...) could be res[illegible] If this was one of many noticeably affected test points, we would have a [illegible] case to say that the reradiators are causing significant distortion to the pattern.

this should be changed to use Eckert's algorithm

APPENDIX D. GROUNDWAVE PROPAGATION LOSS COMPUTER PROGRAM

The following is a listing of the program 'SIGNAL', a BASIC computer program suitable for IBM-PCs and compatibles. The program can be used for scaling field strength values at one distance to another distance based on the ground conductivity, frequency and the relative dielectric strength of the earth. Over-the-horizon effects are ignored as all measurements are assumed to be well within the Norton boundary of 80.467/freq^3 kms (68-98 kms for the AM broadcast band). This program is based on the fortran listing included in Reference #12.

```
10  ' Signal
20  '
30  ' Jan. 27, 1988
40  ' by R.C. Madge, Ontario Hydro Research Division
50  '            800 Kipling Avenue
60  '            Toronto, Ontario   M8Z 5S4
70  '
80  ' This program will take a known field strength value at a known
90  ' distance and calculate a new field strength value at a new distance
100 ' according to an AM GroundWave Propagation subroutine.
110 '
112 ' The program is based on the FORTRAN listing included in Addendum No.2
114 ' to Document No.12-E, Regional Broadcasting Conference, International
116 ' Telecommunications Union, Buenos Aires, 1980.
118 '
120 ' We need to know the frequency, ground conductivity, ground dielect
130 ' field strength value at a known distance, and the new distance.
140 '
150 defdbl z
155 zpi=3.1415926536
157 def fnatan(ga,gb)=atn(ga/gb)+-1*zpi*(gb<0)
160 cls
170 '
180 '*****************************************
190 ' Enter data
200 '
210 input "Enter the frequency in MHz. (0.5-1.7): ";a$
220 freq=val(a$)
230 if freq<0.5 or freq>1.7 then beep:goto 210
240 '
250 print "        5-cities, 10-dry or rocky land, 15-rich farm land"
260 input "Enter the relative dielectric constant of the ground: ";a$
270 dielect=val(a$)
280 if dielect<2 or dielect>80 then beep:goto 250
290 '
300 input "Enter the ground conductivity in mS/m. (.1-20): ";a$
310 gc=val(a$)
320 if gc<.1 or gc>20 then beep:goto 300
330 '
350 input "Enter the distance in kms for known field strength: ";a$
360 dist1=val(a$)
370 if dist1<=0 then beep:goto 350
380 '
400 input "Enter the known field strength in mV/m: ";a$
410 field1=val(a$)
```

```
420 if field1<=0 then beep:goto 400
430 '
450 input "Enter the new distance in km: ";a$
460 dist2=val(a$)
470 if dist2<=0 then beep:goto 450
480 '
500 '****************************************
510 ' Calculate and show the new field strength value.
520 '
530 gosub 1000
540 print:print "New field strength: ";field2;" mV/m"
550 '
560 end
570 '
1000 '*****************************************
1010 ' This routine calculates the f.s. value at a given distance
1020 ' according to known information.
1030 '
1040 ' freq    - frequency in Mhz
1050 ' dist2   - distance at which to calculate new field strength value
1060 ' gc      - ground conductivity
1070 ' dielect - relative ground dielectric
1080 ' field1  - known field strength value at dist1
1090 ' dist1   - distance for known field strength value
1100 ' field2  - new calculated field strength value
1110 '
1120 for dtt=1 to 2
1130   if dtt=1 then d=dist1 else d=dist2
1140 '
1200 x=17.9731*gc/freq
1210 diel2=dielect-1:b1=fnatan(diel2,x)
1220 b2=fnatan(dielect,x):b=2*b2-b1
1230 lamda=.299776/freq
1240 p=zpi*d*(cos(b2)^2)/(lamda*x*cos(b1))
1250 '
1260 '*************************************
1270 '
1280 z1=sqr(zpi):cb=cos(b):sb=sin(b): ps=sqr(p):bs=b/2
1290 z2=2.71828183
1300 cbs=cos(bs):sbs=sin(bs):xx=ps*sbs: yy=ps*cbs:ex=z2^(-(xx^2))
1310 z3=0.3275911:z4=0.254829592:z5=-0.284496736:z6=1.421413741
1320 z7=-1.453152027:z8=1.061405429
1330 '
1340 '**************************************
1350 ' p<.65, b=anything
1360 '
1370 if p>.65 then goto 2000
1380 gama=1:gamo=z1:real=1:aimg=0
1390 i=1
1400 if i mod 2=1 then gamo=gamo*i/2:gam=gamo else gama=gama*i/2:gam=gama
1410 real=real+(ps^i/gam)*cos(i*(bs+zpi/2))
1420 aimg=aimg+(ps^i/gam)*sin(i*(bs+zpi/2))
1430 told=test:test=sqr(real^2+aimg^2)
1440 if i=1 then goto 1460
```

```
1450 if abs((test/told)-1)<.001 then goto 1500
1460 i=i+1:if i=50 then print "Didn't converge.":stop
1470 goto 1400
1480 '
1500 arr=fnatan(aimg,real)
1510 ar=1+z1*ps*test*cos(arr+bs+zpi/2)
1520 ai=z1*ps*test*sin(arr+bs+zpi/2)
1530 a=sqr(ar^2+ai^2)
1540 goto 6000
1550 '
2000 '*************************************
2010 ' .65<p<5, b<zpi/2
2020 '
2030 if p>5 or b>zpi/2 then goto 3000
2040 sect=2:epr=z2^(-(p*cb))*sin(p*sb-bs)
2050 epi=z2^(-(p*cb))*cos(p*sb-bs)
2060 real=1+epr*sqr(p*zpi)
2070 aimg=epi*sqr(p*zpi)
2080 fac=1:ic=1:p2=2*p
2090 i=2*ic-1
2100 af=-1
2110 if ic mod 2=0 then af=1
2120 fac=fac*i:ang=b*ic:fd=af*p2^ic
2130 rold=real:real=real+(fd*cos(ang))/fac
2140 xold=aimg:aimg=aimg+(fd*sin(ang))/fac
2150 test=sqr(real^2+aimg^2)
2160 if ic=1 then goto 2180
2170 if abs((real/rold)-1)<.001 or abs((aimg/xold)-1)<.001 then goto 2300
2180 ic=ic+1:if ic=50 then print "Didn't converge":stop
2190 goto 2090
2200 '
2300 a=test:goto 6000
2310 '
3000 '*************************************
3010 ' 5<p<20, b<zpi/4
3020 '
3030 if p>20 then goto 5000
3040 if b>zpi/4 then goto 4000
3050 sect=3:t=1/(1+z3*xx)
3060 erf=1-(z4*t+z5*t^2+z6*t^3+ z7*t^4+z8*t^5)
3070 re1=ex*(1-cos(p*sb))/(2*zpi*xx)
3080 ai1=ex*sin(p*sb)/(2*zpi*xx)
3090 real=0:aimg=0
3100 f1=2*ex/zpi
3110 '
3120 i=1
3130 cn=z2^(-0.25*i*i)/(i^2+4*xx*xx)
3140 u=i*yy:csh=(z2^u+z2^(-u))/2:snh=(z2^u-z2^(-u))/2
3150 real=real+cn*(2*xx-2*xx*csh*cos(p*sb)+ i*snh*sin(p*sb))
3160 aimg=aimg+cn*(2*xx*csh*sin(p*sb)+ i*snh*cos(p*sb))
3170 told=test:test=sqr(real^2+aimg^2)
3180 if i=1 then goto 3200
3190 if abs(test-told)<.01 and abs((test/told)-1)<.001 then goto 3300
3200 i=i+1:if i=50 then print "Didn't converge":stop
```

```
3210 goto 3130
3220 '
3300 rl1=erf+re1+f1*real
3310 xl1=-(ai1+f1*aimg)
3320 erfcr=1-rl1:erfci=-xl1
3330 erfca=fnatan(erfci,erfcr)
3340 erfct=sqr(erfcr^2+erfci^2)
3350 ept=z2^(-(p*cb)):epa=-p*sb
3360 realt=1+z1*ps*ept*erfct*cos(bs+epa+erfca+ zpi/2)
3370 aimgt=z1*ps*ept*erfct*sin(bs+epa+erfca+ zpi/2)
3380 a=sqr(realt^2+aimgt^2)
3390 goto 6000
3400 '
4000 '****************************************
4010 ' 5<p<20, b>zpi/4
4020 ' .65<p<20, b>zpi/2
4030 '
4040 sect=4:ang=bs-zpi/2
4050 r1=ps*cos(ang):x1=ps*sin(ang)
4060 ra=25+r1:xa=x1
4070 zt=sqr(ra^2+xa^2):az=fnatan(xa,ra)
4080 '
4090 l=2
4100 i=52-l
4110 fa=i/2-.5:ra=(fa/zt)*cos(-az)+r1
4120 xa=(fa/zt)*sin(-az)+x1
4130 zt=sqr(ra^2+xa^2):az=fnatan(xa,ra)
4140 l=l+1:if l<50 then goto 4100
4150 '
4200 fact=1/zt
4210 ar=1+ps*fact*cos(bs+zpi/2-az)
4220 ai=ps*fact*sin(bs+zpi/2-az)
4230 a=sqr(ar^2+ai^2)
4240 goto 6000
4250 '
5000 '****************************************
5010 ' p>20, b=anything
5020 '
5030 sect=5:z10=0.380327:z11=0.03616216: z12=0.1901635
5040 z13=3.5689854:z14=3.1844142: z15=1.7844927
5050 z16=11.0506874:z17=30.5294230: z18=5.5253437
5060 z20=0.4613135:z21=0.09999216: z22=0.002883894
5070 '
5100 rt1=sqr(p^2-z10*p*cb+z11)
5110 bt1a=p*sb:bt1b=p*cb-z12
5120 bt1=fnatan(bt1a,bt1b):bt1=-bt1
5130 rt2=sqr(p^2-z13*p*cb+z14)
5140 bt2b=p*cb-z15:bt2=fnatan(bt1a,bt2b):bt2=-bt2
5150 rt3=sqr(p^2-z16*p*cb+z17)
5160 bt3b=p*cb-z18:bt3=fnatan(bt1a,bt3b):bt3=-bt3
5170 re=(z20/rt1)*cos(bt1)+(z21/rt2)*cos(bt2)+ (z22/rt3)*cos(bt3)
5180 ai=(z20/rt1)*sin(bt1)+(z21/rt2)*sin(bt2)+ (z22/rt3)*sin(bt3)
5190 rt=sqr(re^2+ai^2)
5200 bt=fnatan(ai,re)
```

```
5210 real=1+z1*rt*p*cos(bt+b+zpi)
5220 aimg=z1*rt*p*sin(bt+b+zpi)
5230 a=sqr(real^2+aimg^2)
5240 '
6000 '*******************************************
6010 if dtt=1 then ff=field1*d/a else field2=ff*a/d
6020 next dtt
6030 return
```