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IEEE Guide on the Prediction, Measurement, and Analysis of AM Broadcast Reradiation by Power Lines

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Abstract: A set of procedures to be followed to cope with reradiation of AM broadcast signals from power lines and other large metallic structures is provided. Reradiation may be described as electromagnetic waves radiated from a structure that has parasitically picked up a 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 included.

Keywords: AM broadcast, interference prediction, measurement, power lines, reradiation

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Introduction

(This introduction is not a part of IEEE Std 1260-1996, IEEE Guide on the Prediction, Measurement, and Analysis of AM Broadcast Reradiation by Power Lines.)

This guide 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 that has parasitically picked up a 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 included.

While the procedures listed in this guide 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 frequency sources, such as television broadcast signals. It is anticipated that this guide 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.

In some political jurisdictions, the government regulatory or licensing authority has defined specific procedures for the determination of radiation patterns of medium wave antenna systems. Some of these procedures are also contained in international treaties and agreements, and as such are binding on the licensees of the signatory jurisdictions. When there is agreement between the party or parties who are licensed to operate the medium wave antenna system(s) in question and the parties proposing construction of potential reradiating structures, the procedures of the responsible government agency or authority shall have precedence over the method outlined in this guide.

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IEEE Guide on the Prediction, Measurement, and Analysis of AM Broadcast Reradiation by Power Lines

1. Overview

This guide provides a set of procedures to be followed to cope with reradiation of AM broadcast signals from power lines and other large metallic structures. An AM broadcast array is carefully constructed to radiate strongly towards listeners and weakly in directions where interference to other stations could result. Reradiation can occur when the broadcasted signals are parasitically picked up by a large metallic structure and then rebroadcasted, or reradiated, from that structure. This can result in a decrease in signal towards listening areas and an increase in signal in protected directions. The process of predicting, measuring, and analyzing the interference is complex and nontrivial, necessitating this guide.

This guide is divided into the following sections: interference prediction and limitations, guidelines for taking meaningful field strength measurements, methods of analysing the field strength measurements, and short sections on the application and verification of remedial measures. A series of annexes accompany the guide in order to illustrate the complex analysis.

While the procedures listed in this guide 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 frequency sources, such as television broadcast signals. It is anticipated that this guide 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.

In some political jurisdictions, the government regulatory or licensing authority has defined specific procedures for the determination of radiation patterns of medium wave antenna systems. Some of these procedures are also contained in international treaties and agreements, and as such are binding on the licensees of the signatory jurisdictions. When there is agreement between the party or parties who are licensed to operate the medium wave antenna system(s) in question and the parties proposing construction of potential reradiating structures, the procedures of the responsible government agency or authority shall have precedence over the method outlined in this guide.

2. References

This guide shall be used in conjunction with the following publications. If the following publications are superseded by an approved revision, the revision shall apply.

IEEE Std 100-1992, The New IEEE Standard Dictionary of Electrical and Electronics Terms (ANSI).[1]

ANSI/IEEE Std 268-1992, American National Standard for Metric Practice.

IEEE Std C95.1-1991, IEEE Standard Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz (ANSI).

3. Definitions

Many of the terms used in this guide can be found in IEEE Std 100-1992. The following definitions are either not included in IEEE Std 100-1992 or are specific definitions modified from the general definition to fit this topic more accurately.

3.1 AM broadcast array: One or more towers 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 tower, a far-field pattern can be constructed to broadcast strongly in some directions and weakly in others.

3.2 amplitude modulation (AM): Modulation in which the amplitude of a carrier is caused to depart from its reference value by an amount proportional to the instantaneous value of the modulating wave.

3.3 azimuth: The angle between a horizontal reference direction (usually true north) and the horizontal projection of the direction of interest, usually measured clockwise.

3.4 coverage area: The area surrounding the broadcast array that is within the signal strength contour that provides adequate reception.

3.5 detuners: Devices attached to a structure that alter the impedance at the connection point such that a minimum of current at the design frequency flows in the structure. *Syn*: detuning stub, tuning stub.

3.6 far-field radiation pattern: Any radiation pattern obtained in the far field of an antenna array.

3.7 far-field region: That region of the field of an antenna array where the angular field distribution is essentially independent of the distance from the center of the array. A general far-field approximation is $2d^2/\lambda$, where d is the largest separation between elements in the array.

3.8 field strength: The magnitude of the electric field vector.

3.9 field strength meter: A calibrated radio receiver for measuring field strength. These meters employ a shielded loop antenna, which measures the magnetic component of the electromagnetic field and then converts it to an electric field by multiplying the magnetic field strength by the impedance of free space for a plane wave.

3.10 ground conductivity: A property of the ground, expressed as the ratio of electric current density to electric field strength.

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[1] IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA.

3.11 interference: Field strength produced by a radio disturbance, such as signals from other stations.

3.12 major lobe: The radiation lobe containing the direction of maximum radiation. *Syn*: main lobe.

3.13 minor lobe: Any radiation lobe except a major lobe.

3.14 near-field radiation pattern: Any radiation pattern obtained in the near field of an antenna array.

3.15 near-field region: That part of space between the antenna array and the far-field region. Refers to the field of a source at distances that are small compared to the wavelength.

NOTE—The near field includes the quasi-static and induction fields varying as r^{-3} and r^{-2}, respectively, but it does not include the radiation field varying as r^{-1}.

3.16 nighttime interference: A radio disturbance caused by skywave signals from distant stations. Skywave propagation loss is lowest at night.

3.17 null: The direction between radiation lobes where the signal drops to a minimum. In general, a null is any portion of the pattern where the signal level is less than 10% of the rms of the pattern.

3.18 omnidirectional pattern: A pattern with the same response in all azimuthal directions.

NOTE—This radiation pattern results when only one tower is used to create the radiation pattern.

3.19 proof of performance: The report submitted to the regulatory body, which includes field strength measurements and other information, to show that the measured radiation pattern meets the conditions specified in the station license.

3.20 protections: Limitations imposed on the radiated signal for certain azimuths.

NOTE—These limitations generally are set so that interference does not occur to stations in that direction.

3.21 radial: An azimuth where field strength measurements are taken, starting near the array and extending to well into the far field. Measurements along a radial can be used to establish the radiation in a certain azimuth after allowing for changes other than ground conductivity, such as near field effects, temperature changes, loss or gain due to elevation changes, shadow losses and absorption, and other effects.

3.22 reradiation: The process by which an electromagnetic signal induces currents into a structure, which then causes radiation from that structure.

3.23 rms field: The horizontal component of the root-mean-square (rms) field strength in the far field of an array, scaled to an effective value at 1 km. *Syn*: effective field.

3.24 skywave: A radio wave propagated obliquely toward, and returned from, the ionosphere.

NOTE—This term has sometimes been called an ionospheric wave, but the term “ionospheric wave” is intended to connote internal waves in ionospheric plasmas.

3.25 skywire: Electrically grounded wire or wires placed above phase conductors of an electric line or facility for the purpose of intercepting direct lightning strokes in order to protect the phase conductors from the direct strokes. *Syn*: overhead ground wire.

NOTE—These wires may be grounded directly or indirectly through short gaps.

3.26 test point: A geographic location that has been selected for the measurement of field strength.

3.27 test radius: A circle, with the center of the antenna array as its origin, on which the test points for field strength measurements ideally should be located.

3.28 wavelength: λ. For a monochromatic wave, the distance between two points of corresponding phase of two consecutive cycles in the direction of the wave normal. The wavelength is related to the carrier frequency, f, by $\lambda = c/f$, where c is the speed of light.

NOTE—The wavelength in meters is computed as 300 divided by the frequency in megahertz.

4. Background

4.1 Description

An AM broadcast array is carefully constructed to radiate strongly towards local listening areas and weakly in directions where interference to other stations could result. The strong signals are contained in a major lobe directed toward the local listening area. Other smaller listening areas can be serviced with minor lobes. The directions of weak signals, called nulls, generally are towards areas without listeners, or towards other stations operating at the same frequency (co-channel), at the next highest or lowest frequency (adjacent channel), or at frequencies two channels away (second adjacent channel). The signal shall be weak towards these stations so as to limit the interference to acceptable levels.

As the electromagnetic waves emanating from the radio station travel outward from the antenna array, they may meet various manmade structures containing metal. The passing waves induce electric currents to flow in the metal. These induced currents radiate their own electromagnetic waves at the same frequency as the radio station. The waves produced by the induced currents are called reradiation. The reradiating waves may alter the effective far-field pattern of the AM station. A decrease in received signal can mean a loss of listeners for the station, while an increase can cause the pattern to exceed its allowable limit in certain directions.

Vertical structures are most effective at reradiation when they are close to a quarter wavelength ($\lambda/4$) tall. The AM broadcast band of 535–1705 kHz results in corresponding $\lambda/4$ heights of 140 m to 44 m. This range of heights includes many buildings, transmission line structures, antenna towers, wood poles with vertical ground wires, and even down guys without series insulators. Horizontal structures, such as power lines, also can reradiate signals by picking up current on their tower-skywire-tower loops.

In the case of a power line, reradiation is directly proportional to the AM radio frequency currents in its towers and overhead ground wires. These currents are dependent on the wavelength, tower design, and tower spans. If a loop consisting of two towers, the span between them (provided 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 that causes a high current to flow. As an example, 50 m tall towers with a 200 m span give a loop length of 600 m, which is 2λ for a 1 MHz signal. The loop distance to the second or third tower over can also be of concern.

For power lines without skywires, the tower height in wavelengths and the 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 crossarms. As quarter-wavelengths of AM stations are 44 m to 140 m, there is great potential for resonant 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 3–4 m. 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 less reradiation.

Computer programs can be used to predict the effect of reradiation on AM broadcast antenna patterns. Moment-method programs are the most rigorous, with structures modelled as collections of wire segments. The current in each segment is approximated by a set of current distributions, which are solved to satisfy the boundary conditions. The number of towers and skywires that can be simulated is limited due to the complexity of the problem and limitations in minimum wire separation, computing speed, and computer memory. Transmission-line programs are simpler. The skywire and its image in ground are treated as a transmission line. Current is induced into this transmission line by the incident signal and redistributed according to the tower and skywire impedances. Many more towers and power lines can be modelled using the transmission line method.

None of the available 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 interference and which structures would be ideal candidates for remedial measures.

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

4.2 Proof of performance

When an AM radio station applies for a license, the proposed radiation pattern shall be provided. After the application has been accepted and the installation completed, the results of a proof of performance shall be submitted, with field strength measurements included to ensure that the measured pattern agrees with the proposed one.

The ratio method is a common method radio stations use to establish the shape of a pattern for a proof of performance submission. 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, called an omnidirectional, involves connecting the transmitter to one antenna tower 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.

Ratio measurements usually are made about 15° apart at a sufficient distance to be in the far field. Since the pattern to quantify usually is a smooth and regular shape, the 15° spacing usually is 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 distance, including reradiators, can be as large as 50–100 km, that is, too large for practical measurements. In addition, the pattern shape becomes rougher and more measurements need to be taken, at most every 5° apart, and preferably every 2° to 3°. Also, the time lapse between the beginning of the construction of the potential reradiator and its completion can be in the order of years. Therefore, changes in the surrounding area will be much greater than during a regular proof of performance test.

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

5. AM reradiation guidelines: general procedures

The guidelines have been divided into two categories: potential reradiation problems and existing reradiation 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 is included in this clause. More detailed explanations of each are included in later clauses. The background considerations have been covered at length in other publications, which are cited in the bibliography (clause 11).

5.1 Potential reradiation problems

The following is a general procedure for investigation of potential reradiation from proposed structures. Details of each step will be presented in the clauses mentioned in parentheses.

a) *Simplified prediction (clause 6)*

   The potential reradiation from the structures should be analyzed using either an accepted computer program or the survey technique (see 6.2). Should the prediction indicate a potential problem, then the affected groups should meet to discuss a plan of action.

b) *"Before" field strength measurements (clause 7)*

   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 (very wet or very dry), with the third test taken in the other extreme. However, initial test point selection should not be made with snow covering the ground, since this condition can mask surrounding potential reradiators. For the reasons outlined in 4.2, the results of a proof of performance test for the station may not be used as the "before" pattern.

c) *Remedial measure design (clause 10)*

   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.

d) *"After" field strength measurements (clause 7)*

   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.

e) *Field strength measurement analysis (clause 8)*

   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 at this step.

f) *Structure reradiation measurements—optional (clause 9)*

   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.

g) *Remedial measures or alternatives (clause 10)*

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

5.2 Existing reradiation problems

The following is a general procedure for investigation of potential reradiation from existing structures. Details of each step will be presented in the clauses mentioned in parentheses.

a) *Simplified prediction (clause 6)*
The potential reradiation from the structures should be analyzed using either an accepted computer program or the survey technique (see 6.2). Should the prediction indicate a potential problem, then the affected groups should meet to discuss a plan of action.

b) *"After" field strength measurements (clause 7)*
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 (very wet or very dry), with the third test taken in the opposite extreme. For the reasons outlined in 4.2, the results of a proof of performance test for the station may not be used as the "before" pattern.

c) *Field strength measurement analysis (clause 8)*
The analysis should factor out as many variables as possible, leaving just the effect of the reradiator. The lack of proper before-construction measurement data will make this difficult. If the effect is small enough to be ignored, then the investigation may stop at this step.

d) *Structure reradiation measurements—optional (clause 9)*
Reradiation measurements of the structures may determine if they are radiating a large amount of the AM signal. This information may identify structures most likely to require remedial measures.

e) *Remedial measure design (clause 10)*
If a problem appears to exist, then remedial measures should be investigated. The predictive programs should be able to include in their analysis the various remedial measures and their effects.

f) *Remedial measures or alternatives (clause 10)*
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 the frequency or pattern, altering the structure design, or accepting the consequences of the distortion.

6. 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 cannot take into consideration all practical factors. For this reason, they require some expertise in interpreting the results. However, when properly implemented, they are relatively accurate. The survey technique is quick, self-explanatory, and included as a part of this guide. However, the simplicity of the survey technique necessitates a sizable margin for error, and many structures may be erroneously flagged as interfering structures. Used alone, the survey technique could lead to considerable time and money spent in tracking down structures with negligible reradiation.

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

6.1 Computer programs

Annex 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 strength 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 in the number and sophistication of the modelled towers. Multiline corridors become difficult to handle due to limitations in wire separation distances. In some cases, the limitations become so severe that any analysis is suspect. In these cases, field strength measurements may be the only reasonable alternative.

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 strength levels can be calculated as the sum of the signals radiated from each tower. These programs can handle hundreds of towers and many power lines, but are not as rigorous as the moment method.

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 used, thus preventing false resonances or antiresonances due to identical spans. 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 antenna array 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 licensed pattern requirements and the “after” pattern does not; or
b) The “before” pattern falls outside any of the licensed pattern requirements and the “after” pattern falls significantly farther outside

6.2 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 has to 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 towards 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 national and local rules and regulations, for example, [B4]. *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 practical 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. Annex B contains an example of the reradiation survey technique.

The reradiation ratio represents the percentage of the incident field strength that, when reradiated, will equal the minimum pattern tolerance. Equation (1) determines the reradiation ratio for a given situation.

$$r = \frac{Tol_{\min} \times Dist}{Field \times \lambda} \qquad (1)$$

where

r is the reradiation ratio

Tol_{min} is the minimum pattern tolerance (in V/m)
$Dist$ is the distance to the reradiator (in m)
$Field$ is the 1 km unattenuated field strength in the direction of the reradiator (in V/m)
λ is the wavelength of the radio station signal (in m = $300/f_{\mathrm{MHz}}$)
f_{MHz} is the radio station frequency (in MHz)

Maximum reradiator dimensions can now be determined according to the information in table 1, taken from the *Final Report of the Canadian Department of Communications Working Group on Reradiation Problems in AM Broadcasting* [B11].[2]

Table 1—Maximum allowable reradiator dimensions as a function of reradiation ratio

Reradiation ratio	Maximum structure height (m)	Maximum power line loop length (m)[a]
$r > 0.2$	Structure is acceptable	Power line is acceptable
$0.1 < r$ ð 0.2	$r\lambda$	$(0.94 + 0.3r)\lambda$
0.02 ð r ð 0.1	$(0.025 + 0.75r)\lambda$	$(0.76 + 2r)\lambda$
$r < 0.02$	0.04λ	0.8λ

[a] A loop is formed by two towers, the span between them, and the image in ground.

7. 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 completely the real-world effects that interact to create an actual radiation pattern.

There are three basic methods that can be used to establish the field from a broadcast array: 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 as close to a constant radius from the broadcast array as possible. The radius should ideally be in the far field of the combination of the antenna array and any potential reradiators. By taking measurement sets under widely different ground conductivity conditions, it is possible to observe the effect of ground conductivity on the pattern.

Radial measurements consist of taking up to 20 closely separated measurements on a radial line extending from the center of the array to well into the far field. Usually a minimum of eight 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

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[2] The numbers in brackets correspond to those of the bibliography in clause 11.

taken near the reradiators. This effect would distort the radial profile. Roughly 160 measurements (8 radials times 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 unless airborne measurements are employed; however, proper airborne tests are costly.

Due to the difficulty in estimating ground conductivity from radials in certain conditions, the number of measurements required for this approach, and the cost of proper airborne measurements, users are advised to use one of the other techniques.

7.1 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, such as mountainous terrain. This method includes near-field measurements for monitoring antenna parameters and far-field measurements to identify the pattern shape.

Circular measurements generally consist of 80 or more 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 in the same units as d. However, this can easily become unreasonable. For instance, if d is equal to 3 km and λ is equal to 200 m, the results lead to a far field that is greater than or equal to 90 km. *Therefore, the test radius is defined as 90% of* $2d^2/\lambda$*, but no more than 30 km.* To minimize errors in the analysis, all test points should be as close as possible to the test radius.

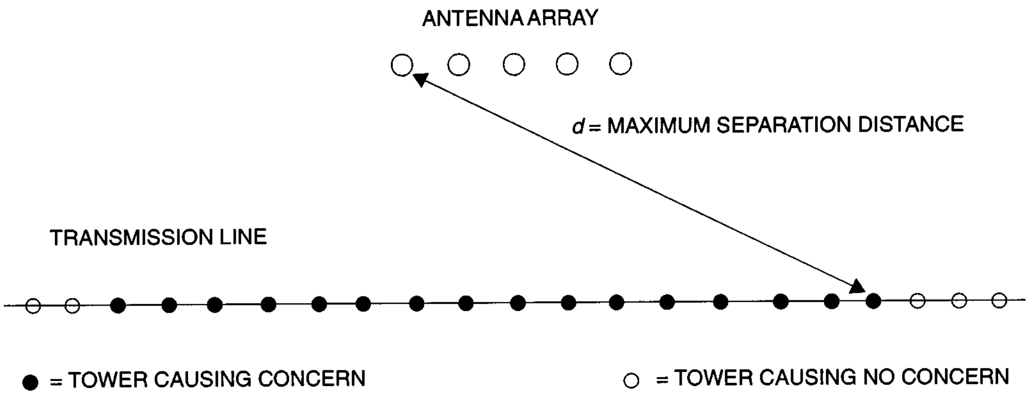

Figure 1—Explanation of maximum separation distance

Figure 1 illustrates this situation. The parties need to identify (through computer simulation, survey technique, or mutual agreement) which structures are of concern. In figure 1, d represents the distance between the two structures that are farthest apart.

Circular measurement test points should be spaced no more than 4–5° apart to quantify rapid azimuthal pattern variations. The only exception may be in the main lobe, where test points can be more widely spaced only if there is no concern over distortion to the pattern coverage. Additional points may be desirable in sensitive null portions of the pattern. Test points should be selected according to the guidelines in 7.3.

7.1.1 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.

- *Measurement set B1*—Taken in one of the ground conductivity extremes, either very wet (high conductivity) or very dry (low conductivity).
- *Measurement set B2*—Taken in the opposite ground conductivity extreme as set B1.
- *Measurement set B1a or B2a*—Taken immediately after either set B1 or B2 to quantify the typical levels of pattern variation.
- *Measurement set A1*—Taken soon after construction, and in ground conditions similar to one of the before-construction tests.
- *Measurement set A2 (optional)*—Taken in the opposite ground conductivity extreme as set A1.
- *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 shall be performed.

- *Measurement set A1*—Taken in one of the ground conductivity extremes, either very wet (high conductivity) or very dry (low conductivity).
- *Measurement set A2*—Taken in the opposite ground conductivity extreme as set A1.
- *Measurement set A1a or A2a*—Taken immediately after either set A1 or A2 to quantify typical levels of pattern variation.

7.2 Ratio measurements

Ratio measurements may be necessary in areas where severe elevation changes, such as mountainous terrain, significantly affect the signal propagation path in certain directions, making circular measurements harder to interpret. 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 80 or more 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. All test points should be between 5 km and 30 km from the array where possible, but no more than 30 km from the array.

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 tower. If possible, the other antenna towers should use filters designed to prevent reradiation from distorting the omnidirectional pattern. The directional mode involves connecting the antenna towers in the normal broadcasting configuration.

Ratio measurement test points should be spaced no more than 4–5° apart to quantify rapid azimuthal pattern 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 guidelines in 7.3.

7.2.1 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.

- *Measurement set B1*—Taken in one of the ground conductivity extremes, either very wet (high conductivity) or very dry (low conductivity).
- *Measurement set B2*—Taken in the opposite ground conductivity extreme as set B1.
- *Measurement set B1a or B2a*—Taken immediately after either set B1 or B2 to quantify the typical levels of pattern variation.
- *Measurement set A1*—Taken soon after construction, and in ground conditions similar to one of the before-construction tests.
- *Measurement set A2 (optional)*—Taken in the opposite ground conductivity extreme as set A1.
- *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 shall be performed.

- *Measurement set A1*—Taken in one of the ground conductivity extremes, either very wet (high conductivity) or very dry (low conductivity).
- *Measurement set A2*—Taken in the opposite ground conductivity extreme as set A1.
- *Measurement set A1a or A2a*—Taken immediately after either set A1 or A2 to quantify typical levels of pattern variation.

7.3 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, various events can occur later that 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 are most likely to be built.

The following set of criteria will help to control factors leading to unnecessary errors. An acceptable point is one that satisfies all eight criteria. A questionable test point will satisfy most of the criteria and will fall slightly short on one or two criteria. An unacceptable test point will be one that significantly fails any one of the criteria, or falls short on more than two criteria.

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

a) 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 has to 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%).
b) Operators should observe the received signal strength within a 20 m radius of the precise test point location. Variations within the 20 m radius of 5% or more on a single meter indicate an unacceptable test point. Variations between 3% and 5% should be noted and the test point flagged as questionable.
c) By rotating the meter's 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 observed at roughly 90° to the orientation that produces the maximum response. 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 pattern is not yet formed. This can cause the minimum signal to be observed at an orientation other than 90° to the maximum signal. A maximum-to-minimum ratio of less than 5:1, or an orientation difference of more than 30° off of 90°, indicates an unacceptable test point. Questionable points have maximum-to-minimum ratios between 5:1 and 10:1, or orientation differences between 10° and 30° off of 90°.

d) All test points should be in visually acceptable locations. There should be no large buildings, antenna towers, or other metallic structures in the immediate vicinity. There also should be no buried pipes or cables. There should be no forests in the immediate vicinity. All wire fences should be at least 20 m away. The distance to all overhead communication and wood-pole power lines without vertical ground wires should be at least 50 m. The minimum distance to wood-pole power lines with vertical ground wires should be 200 m. The minimum distance to steel-tower power-line structures should be 1 km.

e) All test points should be as close to the chosen radius as possible. Significant variations from this will add a further uncertainty, as ground conductivity effects affect measurements at different distances by different amounts.

f) 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 and perhaps markers installed to ensure that the exact location can be found later. A Global Positioning System (GPS) receiver is useful for determining the test locations, which also should be marked on a map.

g) Measurements should take place after sunrise and before sunset only, as interference levels are generally much higher at night than during the day. 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 such conditions may affect the transmitter site and thereby alter the pattern.

h) Where line-of-sight to the antenna array is possible, the maximum signal should be obtained toward the array. A maximum reading away from the array is indicative of reradiation at either 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 then needs to be made regarding 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.

7.4 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 have to 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 be not less than 1 km and not more than 5 km. Care should be taken not to exceed the radiation hazard limits specified in IEEE Std C95.1-1991.

7.5 Factors affecting measurements

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

- *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 array. For this reason, the ground conductivity in the areas of the test points shall be measured during the course of the pattern measurements. This can be accomplished by performing measurements on selected radials leading away from the antenna array.
- *Propagation.* Propagation refers to the way electromagnetic waves travel from one point to another. Since the distances to the test points are large, shadow losses caused by terrain elevations [B3], absorption of signal when travelling over heavily populated areas, and multiple changes in th effective ground conductivity between the transmitter and the test point have to be taken into account.
- *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 their pattern is so strongly affected by small changes in current ratios, impedances, or phase feeds.
- *Power output.* Power output can vary with line voltage and antenna parameter variations. The latter will cause a change in the common-mode impedance, thereby causing a change in effective radiated power. Power changes can even occur with humidity and temperature changes throughout the day, making periodic logging important.
- *Interference.* Noise and co-channel interference can affect the measurement of weak signals, such as may be encountered while attempting to measure the field strength in a null of the pattern. The nighttime interference is usually much worse than the daytime interference, and it is worse in the fall. For this reason, authorization from the appropriate communication authority should be obtained to operate the night pattern during the day for measurement purposes.
- *Temperature.* Large variations in measured signal, caused solely by temperature changes, have been seen at some test points between morning and noon measurements. This type of variation would be greater where lower ground conductivity values prevail.
- *Foliage.* Measurements taken going into and out of a clearing in a wooded area can cause large variations in the observed field strength over relatively short distances.

8. Field strength analysis

Analyzing field strength measurements involves analyzing 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 4.2, the results from a proof of performance test may not be used to establish a “before” condition.

Annex C includes a sample analysis of “before” and “after” tests.

8.1 Individual test analysis—circular measurements

The reduction of raw data to a usable form has to 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.

a) Calculate the average of all meter readings at each test point ($TPAvg_i$).

b) Calculate the average of all test point averages from step a) (*TestAvg*).

c) Calculate the operator error values for tests where more than one operator took measurements. The operator error value represents a crude confidence level that 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 7.2.

   1) Calculate the test average for each meter ($MetAvg_j$).

   2) Calculate the calibration factor for each meter: $CalFac_j = TestAvg/MetAvg_j$.

   3) Disregard all unacceptable test points (labelled as BAD) for the remaining calculations.

   4) Calculate the ideal value for each meter at each test point:

      $Ideal_{ij} = TPAvg_i/CalFac_j$.

      Example: If $CalFac_{\text{meter b}} = 1.05$, then each meter b reading should ideally be 5% above each test point average ($TPAvg_i$).

   5) Calculate the operator deviation ($OpDev_j$) of the sample and maximum positive and negative deviations ($DevPos_j$ and $DevNeg_j$) for each meter for non-BAD test points.

$$temp_{ij} = 100 \times \frac{x_{ij} - Ideal_{ij}}{TPAvg_i}$$

$$OpDev_j = \sqrt{\sum \frac{temp_{ij}^2}{n-1}}$$

where

$DevPos_j$	is the maximum positive $temp_{ij}$
$DevNeg_j$	is the maximum negative $temp_{ij}$
x_{ij}	is the meter reading by operator j at test point i
n	is the number of non-BAD test points

$OpDev_j$ 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.

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

d) Based on the results of step c5), one or more of the meters may have to be rejected. If that is the case, redo steps a) to c), ignoring those meters.

8.2 Individual test analysis—ratio measurements

The reduction of raw data to a usable form has to 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 a) to d) from 8.1 for each of the directional and omnidirectional measurements. Then perform step e) as follows:

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

8.3 Signal fluctuation analysis

The measured field strength from a radio station as recorded by test personnel 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 fluctuation analysis requires that two similar tests be taken in quick succession. This minimizes long-term effects, such as changes in ground conductivity (unless it rained) 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.

a) Determine the absolute value of the difference between the two field strength readings at each test point as a percentage of the first reading (*TPSigFluct*).

$$TPSigFluct_i = 100\left|\frac{TPAvg_{i,first} - TPAvg_{i,second}}{TPAvg_{i,first}}\right|$$

b) Calculate the upper decile cutoff (*SignalFluct*). 10% of the *TPSigFluct* values are greater than this, and 90% are less.

c) If *SignalFluct* is less than 10%, then *SignalFluct* is equal to 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 one compares the same two tests used to quantify *SignalFluct*, one would find that 10% of the test points have differences larger than *SignalFluct*.

8.4 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.

a) Determine the absolute value of the difference between the two readings at each test point as a percentage of the first test (*TPSeasFluct*).

$$TPSeasFluct_i = 100\left|\frac{TPAvg_{i,first} - TPAvg_{i,second}}{TPAvg_{i,first}}\right|$$

b) Calculate the upper decile cutoff (*SeasonFluct*). 10% of the *TPSeasFluct* values are greater than this, and 90% are less.

c) If *SeasonFluct* is less than 10%, then *SeasonFluct* is equal to 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 one compares the same two tests used to quantify *SeasonFluct*, one would find that 10% of the test points have differences larger than *SeasonFluct*.

8.5 Before versus after analysis—circular measurements

An after-construction circular measurement test is compared to a before-construction circular measurement test to determine the effect on the pattern of the presence of the new reradiator. In order to minimize the effects of ground conductivity changes, the “before” and “after” tests should be chosen to have the closest final test average [see step b) of 8.1]. 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.

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

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

$$NewTPAvg_i = TPAvg_{i,\,after} \times factor$$

b) Calculate the pattern deviation value (*PatDev*) 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.

   1) For each test point, the pattern difference at each test point ($TPDiff_i$) can be defined as

      $TPDiff_i = \mathrm{ABS}(TPAvg_{i,before} - NewTPAvg_i) - 0.1$ mV/m

      If $TPDiff_i$ is less than 0, then $TPDiff_i$ is equal to 0.

      The deviation at each test point (*TPDev*) then becomes

      $TPDev_i = 100\ TPDiff_i / TPAvg_{i,before}$

   2) Calculate the upper decile cutoff (*PatDev*). 10% of the *TPDev* values are greater than this, and 90% are less.

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

   If *PatDev* is less than or equal to *SignalFluct*, then the reradiators are minimally detrimental. The analysis stops.

   If *PatDev* is less than or equal to *SeasonFluct*, then the reradiators are marginally detrimental.

   Otherwise, the reradiators can be considered to be noticeably detrimental.

d) The theoretical pattern and all protections to other stations should be scaled out to the test points using acceptable minimum and maximum ground conductivity extremes for the area. 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 any of the parties should be listed.

   The scaling algorithms can be found in [B1] and Annex D. The algorithms require the frequency, ground conductivity, and relative dielectric constant of the ground (see table 2 or the appropriate table in [B9]).

e) 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, $TPDev_i$ from step b1), should be compared to the overall test fluctuation values, *SignalFluct* and *SeasonFluct*, as well as the corresponding individual test point fluctuation values, $TPSigFluct_i$ and $TPSeasFluct_i$ (from 8.3 and 8.4).

   If $TPDev_i$ is less than or equal to *SignalFluct* or $TPDev_i$ is less than or equal to $TPSigFluct_i$, then this test point is minimally affected.

   If $TPDev_i$ is less than or equal to *SeasonFluct* or $TPDev_i$ is less than or equal to $TPSeasFluct_i$, then this test point is marginally affected.

   Otherwise, this test point can be considered to be noticeably affected.

f) 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 nonminimal effects are spaced more than 15° apart, then measurement error may be the cause of the variations.

Table 2—Relative dielectric constants of ground

Terrain	**Relative dielectric constant**
Water	80
Rich farmland, 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

8.6 Before versus 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 minimize the effects of ground conductivity changes, the “before” and “after” tests should be chosen to have the closest final test average (*TestAvg*). 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.

a) Calculate the pattern deviation value (*PatDev*) between the before-construction test and the after-construction test as a percentage of the before-construction test values.

   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.

1) For each test point:

   $TPDiff_i$ = ABS($Ratio_{i,before}$ – $Ratio_{i,after}$) – 0.01

   If $TPDiff_i$ is less than 0, then $TPDiff_i$ is equal to 0.

   $TPDev_i$ = 100 $TPDiff_i/Ratio_{i,before}$

2) Calculate the upper decile cutoff (*PatDev*). 10% of the TPDev values are greater than this, and 90% are less.

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

   If *PatDev* is less than or equal to *SignalFluct*, then the reradiators are minimally detrimental. The analysis stops.

   If *PatDev* is less than or equal to *SeasonFluct*, then the reradiators are marginally detrimental.

   Otherwise, the reradiators can be considered to be noticeably detrimental.

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

d) 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, $TPDev_i$ from step b1), should be compared to the overall test fluctuation values, *SignalFluct* and *SeasonFluct*, as well as the appropriate individual test point fluctuation values, $TPSigFluct_i$ and $TPSeasFluct_i$ (from 8.3 and 8.4).

   If $TPDev_i$ is less than or equal to *SignalFluct* or $TPDev_i$ is less than or equal to $TPSigFluct_i$, then this test point is minimally affected.

   If $TPDev_i$ is less than or equal to *SeasonFluct* or $TPDev_i$ is less than or equal to $TPSeasFluct_i$, then this test point is marginally affected.

   Otherwise, this test point can be considered to be noticeably affected.

e) 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 nonminimal effects are spaced more than 15° apart, then measurement error may be the cause of the variations.

8.7 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 have to be used to indicate expected variations.

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

a) The protections and the theoretical pattern should be scaled out to the test points using acceptable minimum and maximum conductivity extremes for that area. This can be done by taking the unattenuated theoretical field strengths at 1 km or 1 mile, and using the algorithms in [B1], or the BASIC computer program of Annex D, or suitable graphs that can be found in [B10].

b) 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 any of the parties should be listed.

c) Calculate the pattern deviation value ($PatDev_{high}$) 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 $TPAvg_{i,high}$. 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 0.1 mV/m 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.

1) For each test point:

$TPDiff_{i,high}$ = ABS($TPAvg_{i,high}$ – $Theory_{i,high}$) – 0.1 mV/m

If $TPDiff_{i,high}$ is less than 0, then $TPDiff_{i,high}$ is equal to 0.

$TPDev_{i,high}$ = 100 $TPDiff_{i,high}$/$TPAvg_{i,high}$

2) Calculate the upper decile cutoff ($PatDev_{high}$). 10% of the *TPDev* values are greater than this, and 90% are less.

d) Repeat step c) for the low-ground conductivity pattern deviation value ($PatDev_{low}$). If two low-ground conductivity tests took place in quick succession, then use the average of the two measurements as $TPAvg_{i,low}$. If the test point occurs in a direction with a protection to another station, then use the low-conductivity protection value as $Theory_{i,low}$.

e) The pattern deviation values should now be compared with the seasonal and signal fluctuation values to determine if the test could represent a problem.

If $PatDev_{high}$ is less than or equal to *SignalFluct* and $PatDev_{low}$ is less than or equal to *SignalFluct*, then the reradiators are minimally detrimental. The analysis stops.

If $PatDev_{high}$ is less than or equal to *SeasonFluct* and $PatDev_{low}$ is less than or equal to *SeasonFluct*, then the reradiators are minimally detrimental. The analysis stops.

Otherwise, the reradiators may be noticeably detrimental and the analysis continues.

f) Some test points are more sensitive to changes in antenna parameters than others. Therefore, the test point pattern deviation values, $TPDev_{i,high}$ from step c) and $TPDev_{i,low}$ from step d), should be compared to the seasonal and signal fluctuation values, *SignalFluct* and *SeasonFluct* from 8.3 and 8.4, as well as the appropriate individual test point signal fluctuation values, $TPSigFluct_i$ and $TPSeasFluct_i$. Determine the possible effect of reradiation at each test point of concern, as follows:

If $TPDev_{i,high}$ is less than or equal to *SignalFluct* or $TPDev_{i,high}$ is less than or equal to $TPSigFluct_i$, then the test point is minimally affected for high-ground conductivities.

If $TPDev_{i,low}$ is less than or equal to *SignalFluct* or $TPDev_{i,low}$ is less than or equal to $TPSigFluct_i$, 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 $TPDev_{i,high}$ is less than or equal to *SeasonFluct* or $TPDev_{i,high}$ is less than or equal to $TPSeasFluct_i$, then the test point is minimally affected for high-ground conductivities.

If $TPDev_{i,low}$ is less than or equal to *SeasonFluct* or $TPDev_{i,low}$ is less than or equal to $TPSeasFluct_i$, 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.

g) One of the reradiation prediction programs should be run, simulating "before" and "after" cases. *The "before" case shall 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:

1) Determine all directions where the predicted after-construction value is farther from the theoretical value than the predicted before-construction value is.

2) For each direction found in step g1), consider only those directions where the difference between the "after" and "before" values as a percentage of the "before" value is greater than *SignalFluct*.

3) The remaining directions of concern should be cross-referenced with any test points that 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.

h) 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.

8.8 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 have to be used to indicate expected variations.

The following are the steps that will roughly indicate the effect of the reradiators. See 8.2 for a description of ratio measurements.

a) The protections and the unattenuated theoretical pattern should be plotted at 1 km or 1 mi.

b) All measured after-construction patterns should be plotted on the same graph as the protections and the theoretical pattern. The measured patterns should be normalized to have the same rms value as the theoretical pattern rms value (rms_{theory}). The $NewRatio_i$ calculation as follows should be carried out for each test point.

$$rms_{ratio} = \sqrt{\frac{\sum_{i=1}^{n} Ratio_i^2}{n}}$$

$$NewRatio_i = Ratio_i \cdot \frac{rms_{theory}}{rms_{ratio}}$$

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

c) Calculate the pattern deviation value (*PatDev*) between the scaled 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 scaled ratios as $NewRatio_i$. 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.
    1) For each test point:

    $TPDiff_i = \mathrm{ABS}(NewRatio_i - Theory_i) - 0.01$

    If $TPDiff_i$ is less than 0, then $TPDiff_\mathrm{i}$ is equal to 0.

    $TPDev_i = 100\ TPDiff_i / NewRatio_i$

    2) Calculate the upper decile cutoff (*PatDev*). 10% of the *TPDev* values are greater than this, and 90% are less.

d) The pattern deviation value should now be compared with the signal fluctuation values to determine if the test could represent a problem.
    If *PatDev* is less than or equal to *SignalFluct* or *PatDev* is less than or equal to *SeasonFluct*, then the reradiators are minimally detrimental. The analysis stops.
    Otherwise, the reradiators may be noticeably detrimental and the analysis continues.

e) Some test points are more sensitive to changes in antenna parameters than others. Therefore, the test point pattern deviation values, $TPDev_i$ from step c), should be compared to the seasonal and signal fluctuation values, *SignalFluct* and *SeasonFluct* from 8.3 and 8.4, as well as the appropriate individual test point signal fluctuation values, $TPSigFluct_i$ and $TPSeasFluct_i$. Determine the possible effect of reradiation at each test point of concern, as follows:

If $TPDev_i$ is less than or equal to *SignalFluct* or $TPDev_i$ is less than or equal to $TPSigFluct_i$, then the test point is minimally affected.

If $TPDev_i$ is less than or equal to *SeasonFluct* or $TPDev_i$ is less than or equal to $TPSeasFluct_i$, 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.

f) One of the reradiation prediction programs should be run, simulating “before” and “after” cases. *The “before” case shall 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:

1) Determine all directions where the predicted after-construction value is farther from the theoretical value than the predicted before-construction value.
2) For each direction found in step f1) above, consider only those directions where the difference between the “after” and “before” values as a percentage of the before value is greater than *SignalFluct.*
3) The remaining directions of concern should be cross-referenced with any test points that 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.

g) 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.

9. 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.

9.1 Base current measurements

Current measurements can be used to determine the RF current flowing in structures. For structures near a $\lambda/4$ tall, the current at the base of the structure is a quick and easy indicator of the overall current in the structure ([B5] and [B8]). For structures close to a half-wavelength ($\lambda/2$) tall, this 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.

9.2 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 has to 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 have to 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 this 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 has to 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 that cancels itself in the far field and yet strongly affects near-field strength readings.

9.3 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 cannot be used to prove that a reradiation problem exists.

10. 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, effective over a bandwidth of 20 kHz, and 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 [B5]. This is most likely because of the top-loading effect of numerous crossarms parallel to the ground.

10.1 Power-Line tower skywire insulation

Insulation of the 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 [B14]. 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 was measured again. The reduction in base current indicated that a significant reduction in reradiation could be expected. Follow-up field strength measurements verified this.

10.2 Power-Line tower detuning stubs

Detuning stubs may be attached to a power-line tower to alter its effectiveness as an antenna ([B12], [B5], and [B8]). A stub detuner alters the induced current distribution in the tower. By using a $\lambda/4$ 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 create a $\lambda/4$ stub electrically. For stubs less than $\lambda/4$ 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 $\lambda/4$ long requiring no additional reactance at all. For towers over $\lambda/4$ tall, reactive components can be avoided by limiting the stub to a quarter-wavelength. 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 [B12]. 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 2, 3, and 4 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 2) involving a wire similar 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 [B5]. 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 3), which is pulled out from the tower below the conductors [B5]. A nonconducting “wire” has to be used as a guy wire to hold the stub out. One end of this wire would be attached to the stub wire with appropriate hardware, while the other end would need to be securely anchored to the ground away from the tower. The stub wire is terminated with a tuning circuit at the bottom and has achieved 27 dB reduction in base current.

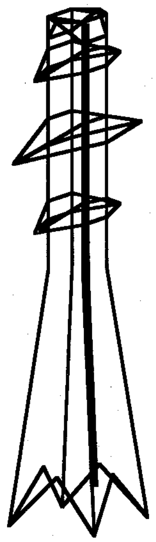

Figure 1—Straight stub on one tower leg

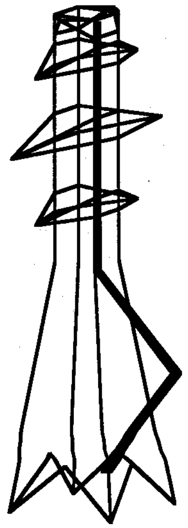

Figure 2—Elbow stub on one tower leg

The best performance can be achieved with the “double-elbow” stub (figure 4). Two elbows 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 [B5].

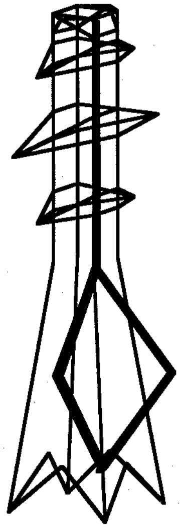

Figure 3—Double-elbow stub on one tower leg

10.3 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 [B14], while full-scale studies have shown them to have serious problems [B5]. 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.

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 has to 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 [B5]. 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 the isolated section should be a quarter-wavelength. 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 [B5].

10.4 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 often have 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.

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.

11. Bibliography

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Annex A

(informative)

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

MiniNEC

PC	Commercially available Also, user interface for MiniNec as provided by ELNEC, contact Roy Lewallen, Beaverton, OR

AWAS

PC	Artech House
attn:	Prof. Roger Harrington

Annex B

(informative)

Reradiation survey example

The reradiation survey from 6.2 and table 1 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 (two 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***

$$\lambda = \frac{3 \times 10^8 \text{ m/s}}{680\ 000 \text{ Hz}} = 440.9 \text{ m}$$

$$r = \frac{Tol_{\min} \times Dist}{Field \times \lambda} = \frac{15 \text{ mV/m} \times 5000 \text{ m}}{1000 \text{ mV/m} \times 440.9 \text{ m}} = 0.1701$$

Since r falls between 0.1 and 0.2:

From table 1, the maximum structure height is equal to $r\ \lambda$, which is equal to 75 m.

The building is acceptable.

b) ***Power line towers***

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

Since r falls between 0.02 and 0.1:

From table 1, the maximum tower height is equal to $(0.025 + 0.75r)\lambda$, which is equal to 38.8 m.

The towers are acceptable.

c) ***Power line loops***

$r = .0839$ (from b)

Since r falls between 0.02 and 0.1:

From table 1, the maximum loop length is equal to $(0.76 + 2r)\lambda$, which is equal to 409 m.

There may be a problem because power line loops are typically 420 m. The situation should now be analyzed using one of the accepted computer programs to determine if a field survey is required.

Annex C

(informative)

Before versus after—circular measurement example

This annex will analyze a simplified reradiation problem. Three "before" tests and one "after" test are included. To keep the sample analysis short, only ten test points will be considered. Table C1 contains the raw data. The procedures for this analysis are listed in clause 8.

Frequency = 1 MHz   Test radius = 10 km

To simplify matters, the relative dielectric constant of the ground for all tests will be kept at 12.

Table C1—Raw data for annex C example

	Test point									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Distance (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										
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										
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										
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

Table C1—Raw data for annex C example

	Test point									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
After Test										
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

C.1 Individual test analysis example—circular measurements

To keep this sample analysis to a reasonable length, only Before Test 3 will be analyzed.

a) Calculate the average of each test point ($TPAvg_i$).

$TPAvg_1 = (108 + 113)/2 = 110.5$ mV/m

$TPAvg_2 = (102 + 108)/2 = 105.0$ mV/m

$TPAvg_3 = (94 + 102)/2 = 98.0$ mV/m

$TPAvg_4 = (96 + 98)/2 = 97.0$ mV/m

$TPAvg_5 = (80 + 81)/2 = 80.5$ mV/m

$TPAvg_6 = (87 + 92)/2 = 89.5$ mV/m

$TPAvg_7 = (97 + 111)/2 = 104.0$ mV/m

$TPAvg_8 = (105 + 115)/2 = 110.0$ mV/m

$TPAvg_9 = (122 + 133)/2 = 127.5$ mV/m

$TPAvg_{10} = (132 + 140)/2 = 136.0$ mV/m

b) Calculate the average of all test points ($TestAvg$).

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

c) Calculate the operator error values ($OpDev_j$, $DevPos_j$, $DevNeg_j$).

1) Calculate the overall test average for each meter ($MetAvg_j$).

$MetAvg_a = (108 + ... + 132)/10 = 102.3$ mV/m

$MetAvg_b = (113 + ... + 140)/10 = 109.3$ mV/m

2) Calculate the calibration factor for each meter ($CalFac_j$).

$CalFac_a = TestAvg/MetAvg_a = 105.8/102.3 = 1.034$

$CalFac_b = 105.8/109.3 = 0.968$

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

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

Example—Test Point 1, meter a

$Ideal_{1a} = TPAvg_1/CalFac_a = 110.5/1.034 = 106.8$

The other values are calculated in a similar fashion.

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

5) Calculate the operator deviation ($OpDev_j$) and maximum positive and negative deviations ($DevPos_j$, $DevNeg_j$) for all non-BAD test points.

$DevPos_j$ = maximum positive $temp_{ij}$

$DevNeg_j$ = maximum negative $temp_{ij}$

$$temp_{ij} = 100 \cdot \frac{x_{ij} - Ideal_{ij}}{TPAvg_i}$$

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

where

x_{ij} is the meter reading by operator j at test point i

n is the number of non-BAD test points = 4

	OpDev **(%)**	***DevPos*** **(%)**	***DevNeg*** **(%)**
Meter a	1.90	2.69	3.42
Meter b	1.90	3.42	2.69

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

Steps a) and b) 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 105.8 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, *SignalFluct*, as described in 8.3. The scaled test point averages used below are derived from the raw data given at the start of this annex. 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**	**$TPSigFluct_i$ (%)**
Test Point 1	102.0	108.5	6.4
Test Point 2	93.0	96.0	3.2
Test Point 3	87.0	94.5	8.6
Test Point 4	86.5	88.0	1.7
Test Point 5	76.5	76.5	0.0
Test Point 6	83.0	87.5	5.4
Test Point 7	96.5	101.0	4.7
Test Point 8	103.0	107.5	4.4
Test Point 9	112.5	123.0	9.4
Test Point 10	124.0	BAD	BAD

The next step is to calculate the upper decile cutoff value (*PatDev*). *PatDev* is defined as the point where 10% of the *TPSigFluct* values are greater than this value, and 90% are less. In this example of only 10 test points, this is best represented by the second largest difference: 8.6%.

Lastly, since the upper decile cutoff is less than 10%, then *SignalFluct* is equal to 10%.

C.3 Seasonal signal fluctuation example

Two tests representing opposite ground conditions are used to determine the seasonal signal fluctuation, *SeasonFluct*, as described in 8.4. 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 that follow are derived from the raw data given at the start of this annex.

Final test averages

Before Test 1: 96.4 mV/m
Before Test 2: 101.3 mV/m
Before Test 3: 105.8 mV/m
After Test: 101.8 mV/m

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.

	BeforeTest 1	**Before Test 3**	$TPSeasFluct_i$ **(%)**
Test Point 1	102.0	110.5	8.3
Test Point 2	93.0	105.0	12.9
Test Point 3	87.0	98.0	12.6
Test Point 4	86.5	97.0	12.1
Test Point 5	76.5	80.5	5.2
Test Point 6	83.0	89.5	7.8
Test Point 7	96.5	104.0	7.8
Test Point 8	103.0	110.0	6.8
Test Point 9	112.5	127.5	13.3
Test Point 10	124.0	136.0	9.7

The next step is to calculate the upper decile cutoff value (*PatDev*). This is defined as the point where 10% of the differences are greater than this value, and 90% are less. In this example of only 10 test points, this is best represented by the second largest difference: 12.9%.

Lastly, if the upper decile cutoff is less than 10%, then *SeasonFluct* is equal to 10%. This proviso does not apply here.

C.4 Before-versus-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 C.3, this is Before Test 2.

a) Scale After Test to Before Test 2.

$$factor = TestAvg_{before}/TestAvg_{after} = 101.3/101.8 = 0.995$$

$$NewTPAvg_{i,after} = TPAvg_{i,after} \times factor$$

b) Calculate the pattern deviation value (*PatDev*). This is the absolute value of the difference between the two tests as a percentage of the first test.

	Before Test 2	**After Test**	**Scaled After Test**
Test Point 1	108.5	87.0	86.6
Test Point 2	96.0	101.5	101.0
Test Point 3	94.5	95.0	94.5
Test Point 4	88.0	92.0	91.5
Test Point 5	76.5	88.5	88.1
Test Point 6	87.5	89.0	88.6
Test Point 7	101.0	107.5	107.0
Test Point 8	107.5	113.0	112.4
Test Point 9	123.0	120.5	119.9
Test Point 10	BAD	BAD	BAD

1) Calculate the difference at each test point.

$TPDiff_i = | TPAvg_{i,before} - NewTPAvg_{i,after} | - 0.1$ mV/m

If $TPDiff_i$ is less than 0, then $TPDiff_i$ is equal to 0.

$$TPDev_i = 100 \times \frac{TPDiff_i}{TPAvg_{i,before}}$$

	$TPDiff_i$ **(mV/m)**	$TPDev_i$ **(%)**
Test Point 1	21.8	20.1
Test Point 2	4.9	5.1
Test Point 3	0.0	0.0
Test Point 4	3.4	3.9
Test Point 5	11.5	15.0
Test Point 6	1.0	1.1
Test Point 7	5.9	5.8
Test Point 8	4.8	4.5
Test Point 9	3.0	2.4
Test Point 10	BAD	BAD

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

   Therefore, *PatDev* is equal to 15.0%.

c) *PatDev* is greater than *SeasonFluct* (12.9%), so the reradiators are noticeably detrimental.

d) The theoretical pattern and all protections and coverages are scaled out the test points according to acceptable minimum and maximum ground conductivity extremes for the area (see [B1] or Annex D). It is often useful to prepare a plot of these patterns and coverage restrictions, as directions of concern are often more easily discerned. These curves are shown in figure C1, along with the before and scaled-after test results. Based on these curves, assume that the participants identify directions towards test points 1, 2, 3, 5, 9, and 10 as directions of concern.

e) Each test point of concern is then to be analyzed according to its measured difference, $TPDev_i$, and signal and seasonal fluctuation values. These have already been calculated.

SignalFluct = 10%
SeasonFluct = 12.9%

	$TPDev_i$ (%)	$TPSigFluct_i$ (%)	$TPSeasFluct_i$ (%)
Test Point 1	20.1	6.4	8.3
Test Point 2	5.1	3.2	12.9
Test Point 3	0.0	8.6	12.6
Test Point 5	15.0	0.0	5.2
Test Point 9	2.4	9.4	13.3
Test Point 10	BAD	BAD	BAD

From the table of deviations, the results show that

$TPDev_1$ is greater than *SeasonFluct* and $TPDev_1$ is greater than $TPSeasFluct_1$, so TP 1 is noticeably affected by the reradiators.

$TPDev_2$ is less than or equal to *SignalFluct*, so TP 2 is minimally affected.

$TPDev_3$ is less than or equal to *SignalFluct*, so TP 3 is minimally affected.

$TPDev_5$ is greater than *SeasonFluct* and $TPDev_5$ is greater than $TPSeasFluct_5$, 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.

$TPDev_9$ is less than *SignalFluct*, 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.

f) As a result of this 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 this example does not allow full and proper study of the situation. If this was the only noticeably affected test point out of 80 test points, one could be tempted to say that other causes (such as local construction near the test point, operator error, antenna parameter changes, etc.) could be responsible. If this was one of many noticeably affected test points, there would be a strong case to say that the reradiators are causing significant distortion to the pattern.

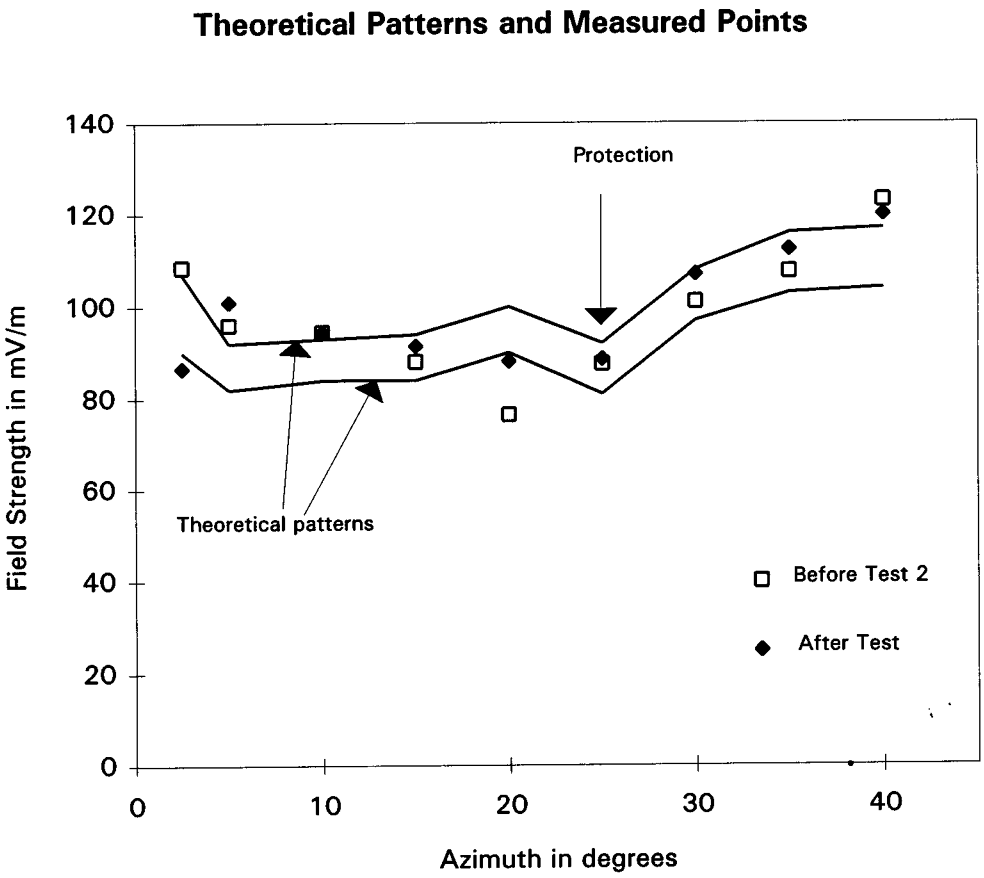

Figure C1—Comparison of theoretical and measured patterns for annex C example

Annex D

(informative)

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, the 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 km (68–98 km for the AM broadcast band). This program is based on the FORTRAN listing included in [B1].

```
10   ' Signal
20   '
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 dielectric,
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 field strength 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)*ex
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
```