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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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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.

¹IEEE 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 denote 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.

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

where

r is the reradiation ratio