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Radio Frequency Interference and Antenna Sites

How much spacing to you really need between antennas at radio sites?

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Collocation and Antenna Spacing Myths

After many years of resistance by wireless licensees, collocation or sharing of antenna sites has recently become a common network buildout strategy. Many collocation opportunities have been missed due to a common industry misconception that fifteen or more feet of vertical spacing is always required between antennas arrays on tower sites. The missed collocation opportunities have resulted in a higher density of towers and more costly network buildouts.

Fifteen or more feet of spacing is sometimes required to prevent interference among systems at antenna sites – the trick is to know when significant spacing is necessary. Without knowledge of the wireless equipment at an antenna site, and use of sophisticated analysis techniques, it is difficult to know how much spacing is really needed. Fifteen or more feet of vertical spacing on a tower has become accepted because it is a safe and conservative estimate.

Actual antenna spacing requirements can be estimated using comprehensive interference analysis techniques. The interference analysis should include investigation of

- Intermodulation and harmonics
- Noise
- Desensitization
- Antenna coupling
- Equipment characteristics

Not Just an Intermodulation Study

Most interference studies performed by radio engineers only consider intermodulation and harmonics and ignore other effects. Typical intermodulation analyses only involve investigating potential combinations of frequencies, an analysis that can be performed using simple software programs. Unfortunately, the results of simple intermodulation analyses do not provide much information – they only indicate whether combinations of frequencies are likely, and provide little or no information on the potential strength of various combinations. A simple intermodulation study, for example, provides insufficient information to determine required antenna separation. In many instances, the vertical spacing among antenna arrays is limited only by physical spacing needed for the antennas. One foot of vertical spacing from antenna tip to antenna tip is often sufficient to prevent interference among systems. Comprehensive interference analysis makes it possible to estimate when this is possible.

Interference analysis makes it possible to collocate antennas more closely together, which make it possible to:

- Collocate more systems on the same tower;
- Use stealth solutions such as a flagpole that require close antenna spacing;
- Reduce the proliferation of towers by collocating more often; and
- Save buildout capital for wireless licensees by making more collocation possible.

Increased Potential for Radio Interference on Antenna Sites

Collocating radio equipment at shared antenna sites creates the possibility of RF interference between tenants at the same site. Factors driving interference include the number of active channels at the site, the relative placement of the antennas, the frequency bands used, and the characteristics of the technology and base station equipment.

Many of the factors affecting the potential for interference between wireless operators have been accelerated by industry trends, including the auctioning of frequency bands by the FCC and the development of new broadband and multi-channel technologies. The probability of interference effects, such as intermodulation, is highly dependent on the number of channels at each site; and, cellular and PCS operators typically transmit many more individual signals per antenna than land-mobile and broadcast operators. The increased density of operators at shared sites is driven by the demand for sites, resulting in reduced antenna separation between tenants, lower isolation between antennas, and increased probability of shared site interference. Much of the newer technology and equipment is also still under development and has not been extensively tested for compatibility in a shared site environment.

These concerns and a lack of understanding of how to address potential interference issues have led to excessive antenna spacing guidelines being applied to all antenna collocations by wireless licensees.

Types of Shared Site Interference

In general terms, interference may be defined as follows:

> *The effect of unwanted energy due to one or a combination of emissions, radiation, or induction upon the reception of a radio system, manifested by the serious degradation, obstruction, or repeated interruption in communication.*

Interference may be generated by sources at a shared site as well as by signals located some distance away from a shared site. Site owners, site managers, and wireless operators typically have little control over interfering signals generated away from the shared site and are therefore limited to concentrating on interference generated by sources at the shared site. Strong signals generated away from the shared site should, however, also be considered where possible.

Interference Mechanisms

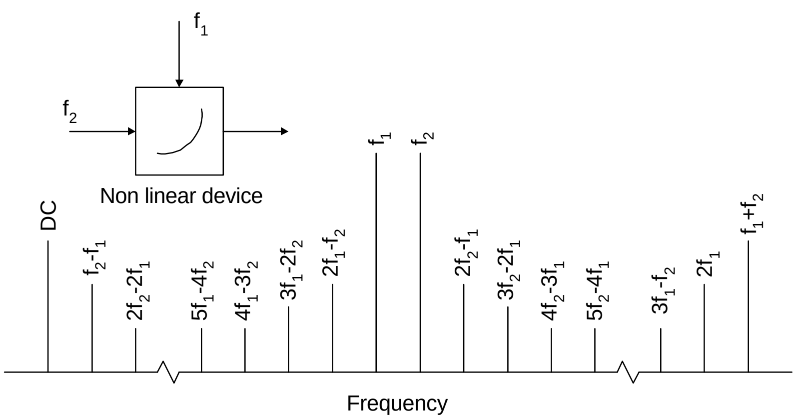
Radio frequency interference at a shared site is typically caused by one of the following mechanisms that have their origin in some form of equipment or other non-linearity:

- Intermodulation
  - Transmitter
  - Receiver
  - Passive
- Out-of-band emissions
  - Transmitter noise
  - Transmitter spurious emissions
  - Transmitter harmonics
  - Receiver spurious emissions
- Other effects
  - Receiver desensitization

Many other mechanisms are also possible and are described in detail elsewhere[1]. One of the most common shared site interference mechanisms is transmitter intermodulation. Signals coupled into the output stage of a non-linear base station transmitter can result in intermodulation products being generated that interfere with other receivers at the site or with mobile receivers near the site. Intermodulation products are generated at frequencies described by the following expression:

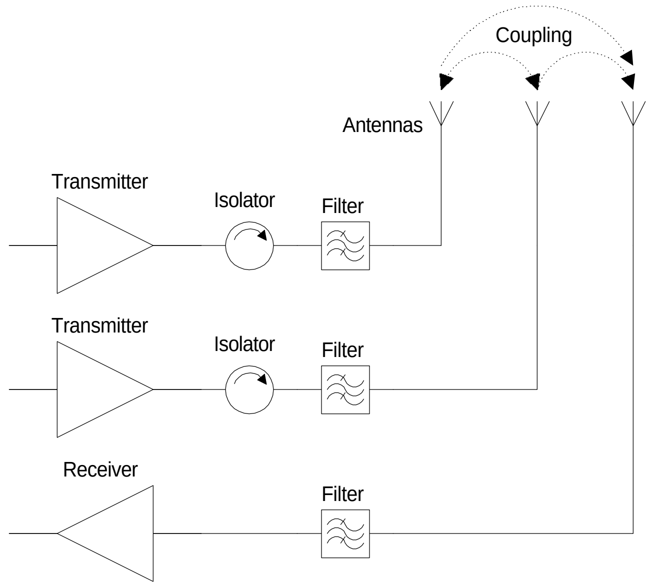
$$f_{intermodulation} = mf_1 + nf_2$$

where m and n are integers and (|m| + |n|) is the order of the intermodulation product. Part of the output spectrum of a non linear device excited by two signals f_1 and f_2 is shown in the following figure.



The most effective way to combat shared site radio frequency interference is to isolate non-linear devices from strong signal sources. As illustrated in the following figure this is typically achieved using a combination of antenna isolation, filtering, and the selective use of more linear devices and ferrite isolators.

[1] J. Gavan, "Main Effect of Mutual Interference in Radio Communication Systems Using Broad-Band Transmitters," IEEE Trans. Electromagn. Compat., vol. EMC-28, no. 4, pp. 211-219, June 1986.



Passive intermodulation can be reduced by minimizing the number of loose metallic joints[2] within system components such as antennas, cables and connectors, and in the external environment on towers and wire fences.

Antenna Site Interference Analysis

Performing a comprehensive interference analysis at shared antenna sites requires good information on the radio equipment and site characteristics as well as use of sophisticated analysis techniques. It is typically not practical to perform a comprehensive interference analysis without using shared site RF interference analysis software.

Historical Development of Shared Site RF Interference Analysis Software

One of the earliest references to shared site RF interference analysis software was the *CO-Site Analysis Model* (COSAM) published by the ITT Research Institute, Electromagnetic Compatibility Analysis Center (ECAC), in 1970[3]. This software, developed primarily for naval shipboard applications, was followed in 1978 by the development of two software modules called *DEsign Communication ALgorithm* (DECAL)[4], and *Performance Evaluation (Communication) ALgorithm* (PECAL)[5]. Other software developed during this period included *Shipboard ElectroMagnetic Compatibility Analysis* (SEMCA), developed by

[2] P. L. Lui, “Passive intermodulation interference in communication systems,” Electronics and Communication Engineering Journal, pp. 109-118, June 1990.
[3] M. N. Lustgarten, “COSAM (Co-site Analysis Model),” IEEE Electromagnetic Compatibility Symposium Record, Anaheim, California, pp. 394-406, July 1970.
[4] J. W. Rockway, and S.T. Li, “Design Communication Algorithm (DECAL),” IEEE International Symposium on Electromagnetic Compatibility, Atlanta, GA, pp. 288-292, June 1978.
[5] L. C. Minor, F. M. Koziuk, J. W. Rockway, and S.T. Li, “PECAL: A New Computer Program for the EMC Performance Evaluation of Communication Systems in a Cosite Configuration,” IEEE International Symposium on Electromagnetic Compatibility, Atlanta, GA, pp. 295-301, June 1978.

General Electric and Atlantic Research Corporation[6], and *Interference Prediction Model* (IPM), developed by Litton[7].

In 1989, the Telecommunications and Information Sciences Laboratory at the University of Kansas published a paper on a *Communications Engineering Design System* (COEDS)[8]. COEDS was a software shell written around the ECAC software that consisted of a graphical user interface, database managers and a performance evaluation post processor. The Mitre Corporation published a paper in 1990 on the *Cosite Analysis Platform Simulation* program (CAPS)[9].

All the software mentioned so far was developed for the military and is either not available or is not directly suitable for commercial applications. Prior to the development of the UNIstar software described later, no comparable software known to the author has been developed for commercial applications, apart from a program called *ComSitePlus* developed by Douglas Integrated Software[10].

UNIsite's Shared Site RF Engineering Software - UNIstar

UNIsite has developed a software tool called UNIstar to meet the need for effective shared site RF interference analysis and engineering. UNIstar consists of an equipment database, a site interference analysis module, and multiple graphical user interfaces. The database is a key feature of the software and includes both site related tenant information, such as the site equipment and the antenna locations, as well as interference-related specifications for a wide range of base station equipment made by different manufacturers.

User Interfaces

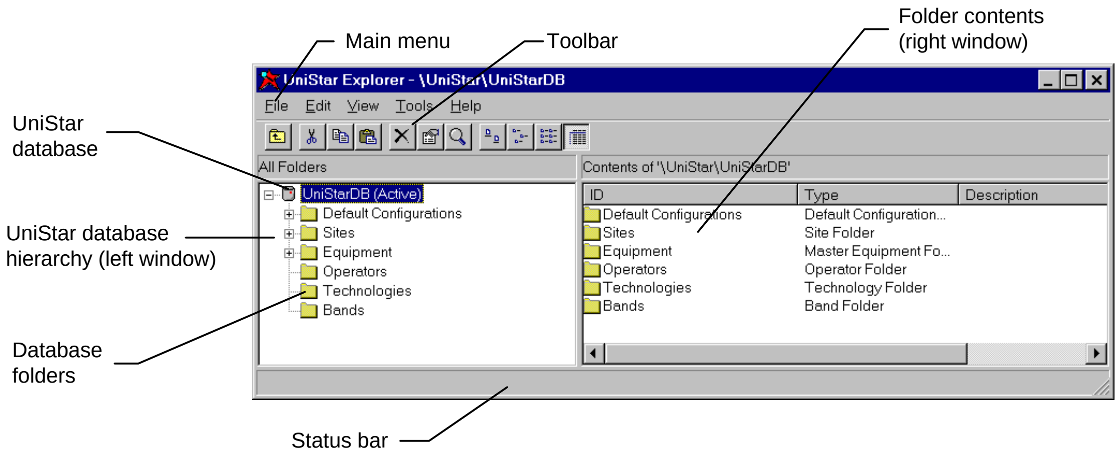
The primary user interfaces to UNIstar include:

- An interface to the UNIstar database called UNIstar Explorer;
- A Block Diagram Editor used to construct circuits, specify equipment models, and define transmit and receive frequencies;
- A Curve Graph Editor to characterize equipment with a set of curves; and
- An Antenna Placement interface to define towers and building structures and the type and placement of antennas on the structures.

UNIstar Explorer

UNIstar Explorer is the gateway into the UNIstar Database, development tools, analysis engine, and report generator. UNIstar Explorer provides a means to construct and manage your UNIstar Database, as well as run an analysis and generate reports. The analysis reports

[6] R. P Bouchard, A. J. Heidrich, R. R. Raschke, and J. T. Sterling, "Shipboard Electromagnetic Compatibility Analysis, SEMCA (V) User's Reference Manual," vol. 10A, General Electric Co. December 1973.
[7] J. C. McEachen, "Topside EM Environment Analysis in Designing the DD-963 Class Ship," IEEE International Electromagnetic Compatibility Symposium Record, pp. 155-162, July 1972.
[8] P. Alexander, P. Magis, J. Holtzman, S. Roy, "A methodology for interoperability analysis," IEEE Military Communications Conference (MILCOM 89), Boston, MA, pp. 905-910, Oct. 1989.
[9] J. Low and A. S. Wong, "Systematic approach to cosite analysis and mitigation techniques," Proceedings of the Tactical Communications Conference, vol. 1, pp. 555-567, April 1990.
[10] ComSitePlus User Manual, Douglas Integrated Software, Tallahassee, FL, 1995.

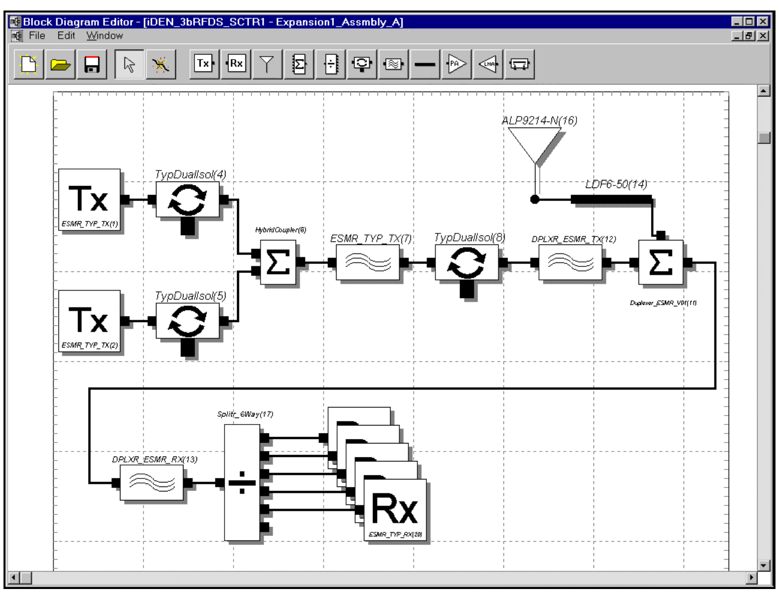


and user documentation are also stored in the UNIstar database and managed by UNIstar Explorer.

Block Diagram Editor

UNIstar models radio systems as a collection of circuits represented by block diagrams. The block diagrams show radio equipment and their connections. The Block Diagram Editor allows users to construct their own circuits, specify equipment models, and define transmit and receive frequencies.

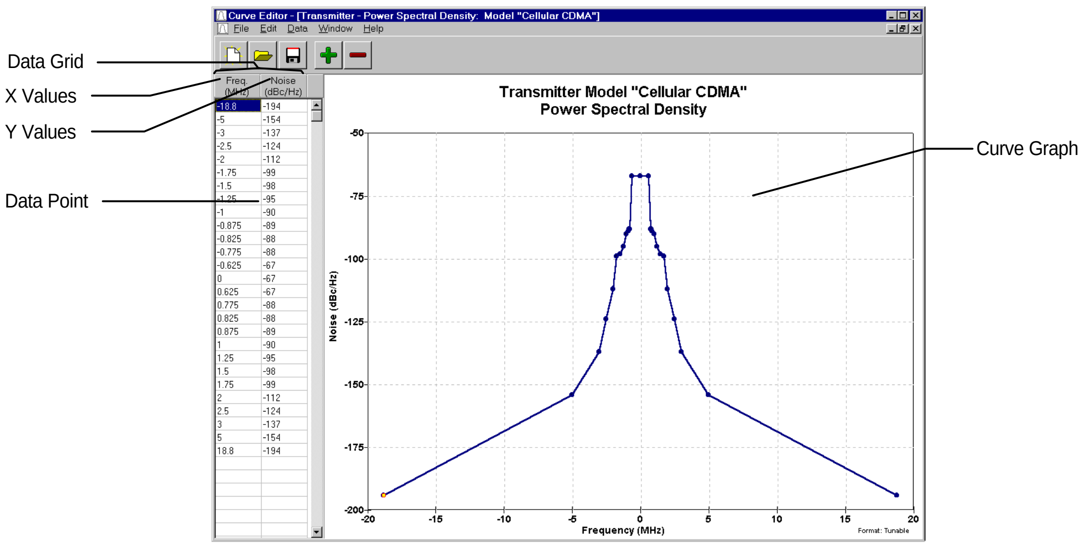
The UNIstar system uses electrical and physical models of a site to predict shared site interference. These models include equipment characterization, radio system designs, and antenna mounting. The Block Diagram Editor interface shown below is the primary tool for building and customizing the radio system models.



UNIstar models a radio system with a set of circuits composed of interconnected equipment. A group of related circuits is called a system configuration, or just configuration. A block diagram is used to depict each of the individual circuits in a configuration. These circuits define the equipment used and the current path from an antenna to a transmitter or receiver.

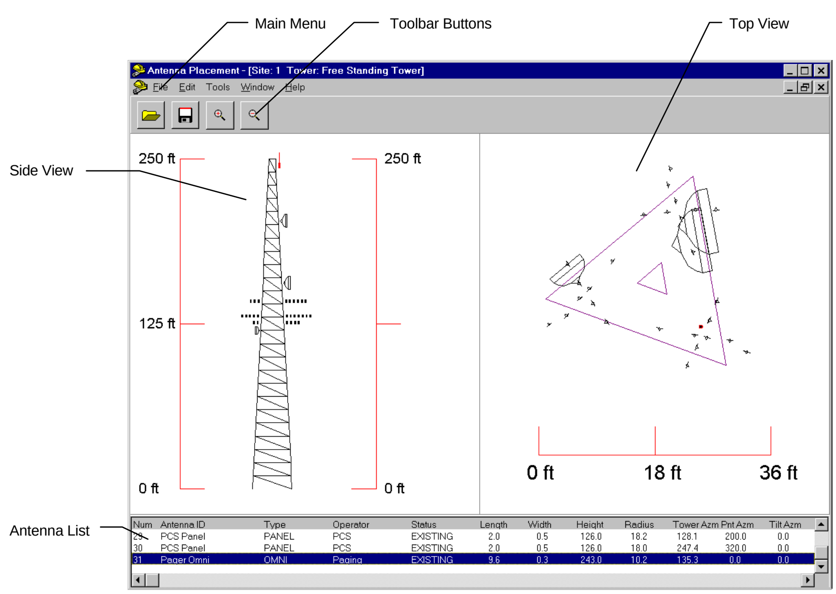
Curve Graph Editor

To model equipment effectively, UniStar characterizes equipment with a set of characteristic curves. A curve may represent a range of characteristics -- from the loss through a filter across the frequency spectrum to the conversion loss within a transmitter for different intermodulation orders. With the Curve Graph Editor, shown below, one can modify these characteristic curves.



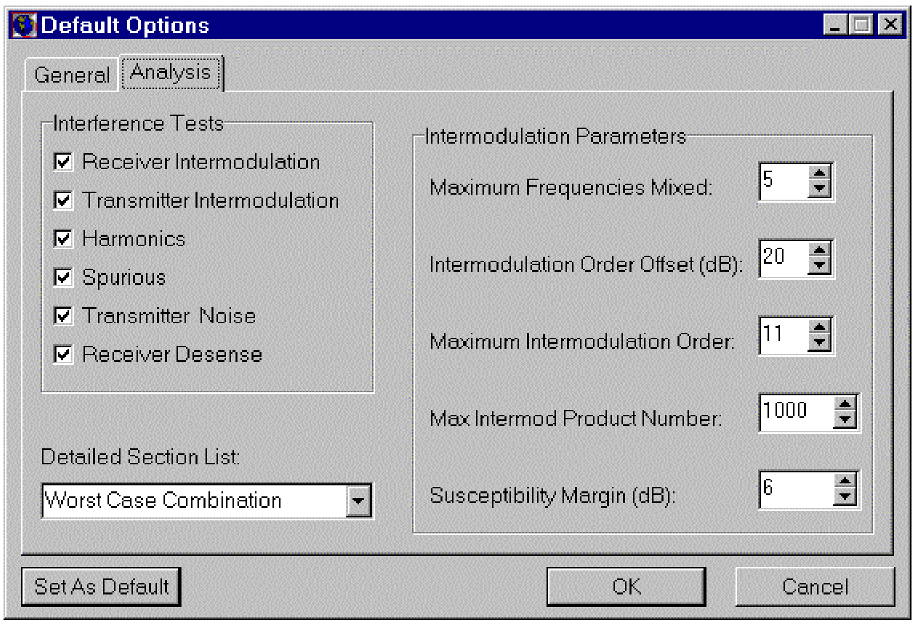
Antenna Placement

UNIstar uses the physical placement of antennas to calculate the coupling between them. This coupling is used to predict site interference and radiated power density. The Antenna Placement interface is shown below. This interface displays a tower or rooftop and all corresponding antennas at the structure.



Site Interference Analysis Module

The Site Interference Analysis Module (SIAM) predicts and reports six types of shared site interference: transmitter noise, receiver desensitization, transmitter intermodulation, receiver intermodulation, harmonics, and spurious emissions. The analysis options page allows the engineer to modify various analysis parameters.



The software algorithms are sufficiently flexible to analyze the arbitrary configurations defined by the user. One significant feature of SIAM is an efficient intermodulation algorithm that reduces the number of potential frequency combinations required to be considered by first analyzing if the worst case interactions between two systems is likely to create an interference problem. If the worst case interaction is unlikely, the less likely combinations may be ignored to decrease the computation time.

Report Generator

The UNIstar software includes a report generator that invokes Microsoft Word to build a detailed report that includes graphics of the antenna site. The report describes whether or not interference is likely to occur and provides sufficient information to enable an engineer to identify the circuits likely to cause interference.

Conclusion

The answer to the question of *how much spacing one really needs between antennas at radio sites* depends on the configuration of each individual site. Analysis and practice have shown that the fifteen or more feet of vertical antenna spacing, used as a general guideline by wireless operators, is not always required. In many cases only the physical dimensions of the antennas dictate the antenna spacing requirements. However, without detailed information on the site, and use of sophisticated analysis software, it is difficult to know when significant spacing is needed, and even more difficult to know how what the minimum spacing requirements are, particularly on antenna sites with many collocated systems. Use of sophisticated software tools such as UNIstar makes it possible to analyze whether interference is likely on shared antenna sites, and also makes it possible to optimize the antenna placement to accommodate far more antenna systems than would be possible using generally adopted antenna spacing guidelines. Minimizing antenna spacing provides a number of benefits including: collocating more systems on the same tower; using stealth solutions such as a flagpole that require close antenna spacing; reducing the proliferation of towers by collocating more often; and saving buildout capital for wireless licensees by making cost effective collocation possible.