Report WG 8.93.009

REFLECTION PREDICTION:
TUTORIAL for MICROWAVE SCATTERING INTERFERENCE MECHANISMS

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Final Draft
September 29, 1993
(Reprinted January 2005)

2000 Source: Working Group 8

National Spectrum Managers Association

Working Group 8 – Reflection Interference

Tutorial

Microwave Scattering Interference Mechanisms

Forward

This tutorial has been prepared by the members of NSMA Working Group 8 in an effort to further an understanding of microwave reflection interference among those new to coordination work and also among more experienced coordinators and radio engineers.

It is intended that as more information becomes available, particularly with regard to practical experience with reflective paths and measured data, this document will be updated to include the new material.

Working Group 8's members would like to invite participation in their meetings by anyone interested in learning more about the prediction and avoidance of reflection interference and by those wishing to make a contribution to the art by sharing their research and practical experiences with others of similar interest.

Larrie Sutliff
Chairman

Editorial Note: This document is a reprint of the original final draft dated September 29, 1993. No electronic softcopy file of the original document could be found; therefore, this document was reprinted (retyped) to accommodate the electronic transfer of this tutorial report. Some of the text has become dated because of subsequent Federal Communications Commission changes for the use of the 2 GHz band and the decommission of most 4 GHz terrestrial stations. Working Group 8 is inactive at this time, although the NSMA would welcome additional input from interested parties. The NSMA web forum is available for postings on this subject. (Look for the forum tab on the NSMA web site at www.nsma.org.)

A few minor editorial changes were made in the reprinted document. Appendix 1 (referenced on page 5) was not included in the final draft and therefore, is not available in this reprint document. Some of the examples of reflection problems in Section VII. could not be reproduced from the final draft; however, the three situations included in this reprint are representative of terrain scatter problems that have been documented.

dlg 1/31/05

Microwave Scattering Interference Mechanisms

I. Introduction

Just as light from a source is reflected by the surfaces that it illuminates, microwave energy from an antenna, which illuminates an area much larger than the intended receiving antenna, is scattered or absorbed by the surface that it falls upon. Under the right conditions, some of the scattered energy may be intercepted by the antenna of a microwave receiving system operating on the same or an adjacent frequency. When sufficient energy from the unwanted signal is intercepted, this interference can degrade the performance of the affected system. The amount of signal that is intercepted depends on a number of factors including the physical relationship of the interfering transmitter and the victim receiver, the amount of energy reflected and the characteristics (signal strengths, loading, digital or analog, polarization, etc.) of both signals.

The frequency coordinator's challenge, of course, is to predict when a probability of reflective interference exists, before a system is constructed, and to do so economically. Since careful evaluation of a path for potential reflection problems can require considerable computer time and engineering effort, most coordinators attempt to cull those few paths that could present a problem from the large number that are described in the prior coordination notices (PCNs) that they receive each year. This is generally accomplished with some sort of mechanized screening tool, carefully designed to identify all possible reflective path candidates without spending a large amount of computer time evaluating each one. As a practical matter, replies to PCNs evaluated for protection of incumbent systems will generally contain a conditional approval noting any reflection interference potential identified by the respondent. This accomplishes two goals—it puts the new system designer on notice that a potential for reflective interference exists and a more careful evaluation may be in order, and it transfers the burden for subsequent reflective problems from the approving incumbent to the new entrants.

Potential sources of interfering signals, of course, include all intentional and unintentional radiators producing energy of sufficient strength to be harmful to the victim receiver. Proposals to share point-to-point microwave bands with personal communications system base units and hand held transceivers add the dimension of mobility to potential interference sources. When movement of the interfering source is combined with a multitude of reflective paths between interfering transmitter and victim receiver, the interference modeling can become very complex.

In the following sections, we discuss the physical factors affecting reflection, techniques that have been found effective in predicting and avoiding the phenomenon, and examples of problems that have been encountered and documented. In addition, we have included a synopsis of the activities to date of NSMA Working Group 8.

II. Working Group 8 – Reflection Interference Prediction

Working Group 8 is actively pursuing a number of issues related to (1) improving the science of predicting reflected microwave interference, (2) improving the accuracy of computer programs used for coordination computations and (3) facilitating the development of educational material and tutorial presentations regarding this type of interference for the benefit of the NSMA membership. This work is furthered by technical presentations from those conducting research related to reflection interference and from those developing systems for the processing and management of reflection prediction information. In addition, situations encountered and data gathered in the course of the day-to-day activities of working group members are frequently shared in the interest of benefiting the industry.

By way of facilitating information exchange regarding reflective calculations, the group has examined prior coordination notice language used by coordinators with an eye toward its standardization and development of a common understanding of its meaning. This has led to a more uniform interpretation of this information.

In addition, the working group is trying to develop a basis for comparison among the models used to forecast reflective interference. Various algorithms and computer-based models are currently being used among coordinators to predict potential reflective situations, but the mathematical details are frequently considered proprietary. In order to permit comparison, improvement and validation of these different models without a theoretical analysis, a standardized set of reference paths is being assembled to which the mechanized predictive programs may be applied. These reference paths, on which measured data regarding reflected energy is available, are being contributed by members of the group for the benefit of all. Comparison of each model's output to the known data is expected to produce an indication of the model's accuracy. It has been suggested that publication of these results could enhance the confidence of receiving coordinators in the reflection predictions sent to them and therefore facilitate the information exchange process.

The group has prepared this written tutorial material and supports periodic seminar sessions designed to further understanding of reflective phenomena among the NSMA membership.

III. Reflection Mechanisms and Factors Affecting Reflective Behavior

Reflective interference occurs when microwave radio signals bounce off an object towards an unintended receiver. There are two very different mechanisms that cause these reflections, specular reflection and diffuse scatter.

Specular Reflection

This type of reflection behaves very much like an optical reflection, where energy striking a highly reflective flat surface is redirected back at a single angle. To illustrate this, imagine a flashlight shining off a mirror in a darkened room. The reflected beam illuminates only those things that lie along the beam's path.

Diffuse Scatter

Diffuse scatter differs from specular reflection in two ways; where specular reflection requires a relatively flat surface, diffuse scatter can occur from any surface, and where specular reflection is redirected at a single angle, diffuse scatter is reflected at all angles. An example of diffuse scatter is moonlight. Although the moon is neither flat nor smooth, it reflects sunlight very effectively and in all directions. The degree of illumination depends only upon how much of the moon's visible surface is illuminated by the sun, ranging from new moon to full.

Shadowing

The concept of shadowing is important in the estimation of reflection interference. An area or region on the surface of the Earth can contribute to the interference from a transmitter to a receiver only if it is visible to both. Any area that does not satisfy the visibility condition is said to be shadowed. Two types of shadowing have been identified and described in the literature; these are macro-shadowing and micro-shadowing.[1] A region that could contribute to the scattering interference is said to be macro-shadowed if the line-of-sight path from this region to either the transmitter or the receiver is blocked. Micro-shadowing occurs when a region is not visible because of its orientation with respect to either the transmitter or the receiver. Both micro-shadowing and macro-shadowing are significant for the estimation of reflection interference.

Frequency Reuse Patterns

An important factor affecting the probability of encountering reflection problems is the manner in which frequencies are reused. Generally, at a single location, one portion of a band is designated for transmitting while a different portion of the band is designated for receiving. When stations are operated contrary to this practice, they are known as "bucking" stations.

The 2 GHz, 6 GHz, and 11 GHz Common Carrier bands are each divided into two equal bandwidths of channel assignments. At 6 and 11 GHz, the low and high band groups are separated in the center by a small "guard band." The 2 GHz band has another service assigned between the low and high band segments. The 4 GHz Common Carrier band uses an interleaved

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[1] Andrew L. Kahn, Vasant K. Prabhu, and William Turin "Shadowing Algorithms in Estimating Ground Scatter Interference," IEEE International Conference on Communications (ICC'92) pp 350.1.1-350.1.4 (1478-1481).

frequency plan with transmitters and receivers separated by 20 MHz. Our discussion is limited to the 2, 6, and 11 GHz bands but it applies equally to the 4 GHz band.

In long haul service, each terminal and repeater station normally receives in one half the band and transmits in the other half. Using this scheme, in the 500 MHz wide 6 GHz band, it is possible to transmit and receive a 240 MHz bandwidth of message services (8 message channels of 30 MHz), with two 2-way narrow band orderwire channels at the band edges.

When building a new route between two existing junction stations, with the fewest repeater stations between them, a bucking repeater station may have to be included in order to match the frequency assignment plan at each of the junction stations. That is, the bucking station will retransmit the signals on the same frequencies on which they were received. To get the needed isolation between transmitters and receivers operating on the same frequencies, the equipment is located in an RF shielded screen room. Also, the station location is selected so that there is an optimum angle (dogleg) between the two paths at the repeater station to prevent line-of-sight interference between the two stations adjacent to the repeater station during high values of K.

This meaning of bucking also applies to terminal stations in cities. These bucking stations may belong to any number of carriers. Although the individual stations may not buck in themselves, the high/low pattern of all the stations in the city do not match. It is common practice to designate a city as either high or low transmit for each band, based on the first microwave system built in the band. Any subsequent carrier is expected to match the established high/low pattern. This is to prevent interference from reflections off the many large buildings within the city that act much like passive repeaters.

Interference from bucking stations in cities has proven intolerable in many instances. Some argue that with all the "working" city bucks, it is an accepted practice. However, most times that a proposed bucking station is properly simulated, the resulting predicted interference proves unacceptable. Also, it is difficult to obtain measurements from companies who are accepting interference from bucks that they would not normally tolerate in initial system design.

IV. Models for Reflective Interference Prediction

Overview

Various algorithms and computer-based models are currently being used among coordinators to forecast reflective interference, but the mathematical details are frequently considered proprietary. These models generally operate by first screening path designs for possible reflective situations and then more carefully examining those proposals that have been flagged by the initial screening process. An important objective served by this iterative process is to manage the cost of reviewing each proposal for potential reflective situations while, at the same time, adequately examining those situations that show a probability of reflective interference.

Most terrain scatter models are based on the bistatic radar equation shown below. Different values of the coefficient of reflection, σ, are used; this parameter may be modified to fit the function of the particular mode. In addition, the model controls the size of the study area—this varies among models and may be manipulated for different types of analysis.

Bistatic Radar Equation:

The bistatic radar equation for the received power scattered from an object or element with physical area A is given as follows:

$$P_r = P_t \frac{\lambda^2}{(4\pi)^3} \frac{G_t G_r}{R_t^2 R_r^2} \sigma A$$

Definition of Terms:

A	Physical area of scatterer
P_t	Transmitted power
P_r	Reflected power
G_t	Gain of transmitting antenna
G_r	Gain of receiving antenna
R_t	Distance from transmitting antenna to reflective media
R_r	Distance from receiving antenna to reflective media
σ	Coefficient of reflection
λ	Wavelength

A description of a method of determining the total scatter power contributed by the terrain in an extended geographic area is given in Appendix 1. (See editorial note on page ii.)

Brief descriptions of the screening approaches used by some frequency coordinators are given below.

AT&T Model

AT&T utilizes a computer model that predicts reflective interference that results from diffuse scatter off both natural and man-made terrain features. This terrain scatter model, called TERSCAT, is used by AT&T to engineer their own paths and to evaluate competitor's prior coordination notices.

In addition to the standard parameters required to calculate direct coupled, or great circle, interference, parameters such as the locations, antenna characteristics, and transmit powers of the wanted and interfering paths, TERSCAT also requires knowledge of the surrounding terrain, both elevation and coverage type, and the location, height, and type of neighboring man-made features.

Each terrain feature is evaluated as a discrete scatterer and its interference contribution is calculated. The total predicted reflective interference level is simply the sum of all the contributors.

Currently, United States Geological Survey 15 arc second level 1 digital elevation data is used. The resolution of the data, that is, the distance between adjacent data points, is 15 seconds of latitude or longitude—about 1/4 mile. Level 1 refers to the source of the data, which is 1:250,000 scale topographic maps.

Two factors that affect the accuracy of TERSCAT are the accuracy of the terrain data and size of the analysis area—about 60 miles by 60 miles.

Comsearch Model

The Comsearch Terrain Scatter model is based on the bistatic radar equation. The scattering coefficient, σ, used in the equation is based on the Comsearch city radius model. This model approximates the extent that buildings—which may be reflecting surfaces—stretch out from the city center. The model assumes a city reflection coefficient if within the city radius and a rural coefficient outside that radius. The radius is proportional to population.

The area used in the equation is based on the 3 dB beamwidth crossing of both the interfering and interfered antenna (see diagram on next page). If the paths do not cross, a worst case value is found by calculating the scattering from the transmitter's sidelobes at points along the victim receiver's antenna boresight.

The 3-dimensional antenna pattern of the antennas involved are approximated by the horizontal plane pattern. Scattering points in the sidelobes of both the interferer and victim are currently assumed to be negligible second-order effects and are ignored.

Integration

The defined scatter area can be divided into small cells so that the C/I can be computed for each cell to determine the worst case (profiling using digitized terrain data is performed from each cell to the respective transmitter and receiver). The effects of shadowing are considered and the composite C/I is calculated.

Predicted vs. Measured

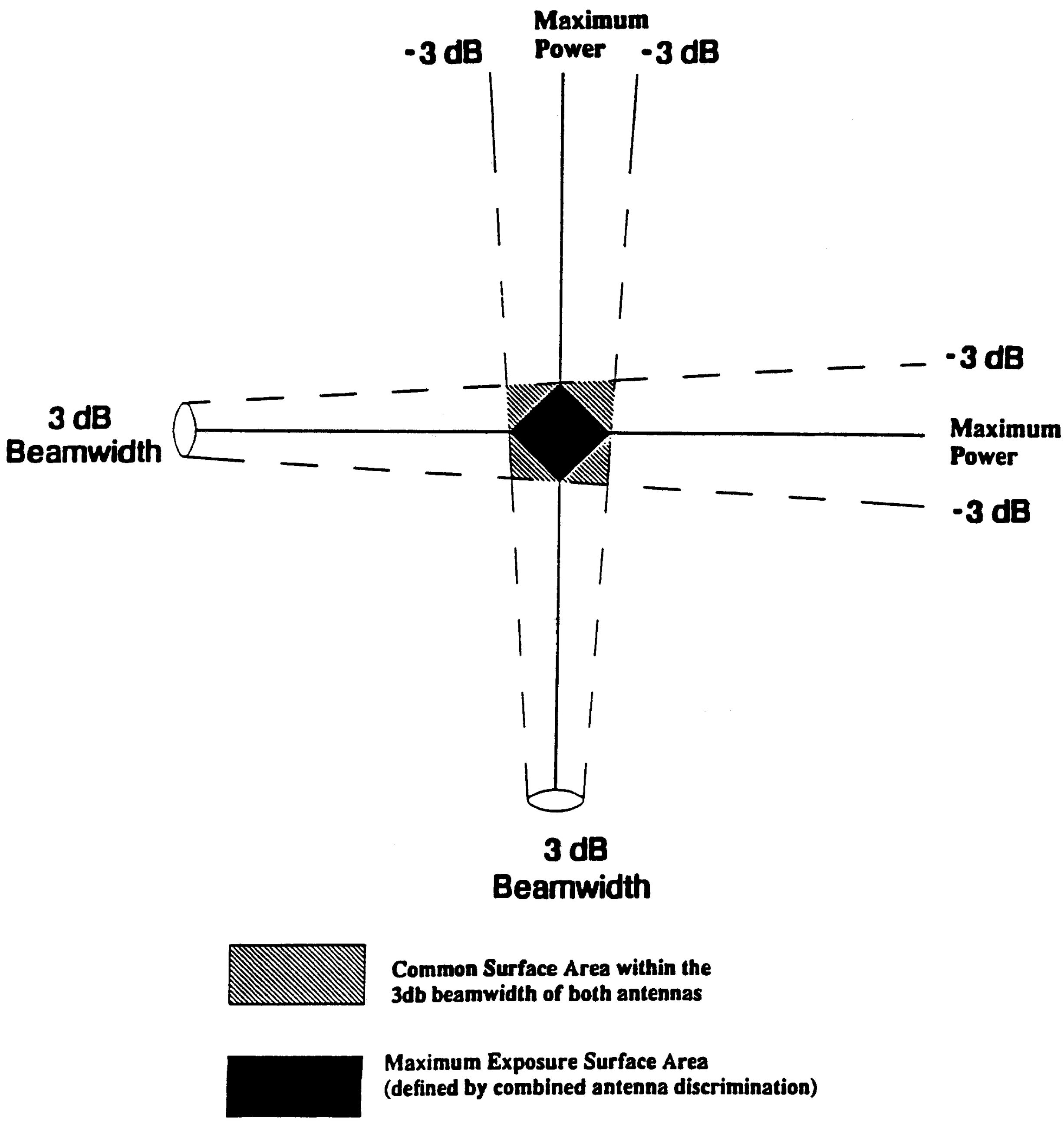
A sample group of 20 scattering cases at 4 GHz was analyzed to determine the correlation between predicted and measured ratios of wanted to unwanted signals. The 20 cases were selected on the basis of LOS conditions in rural areas to minimize the effects of terrain shadowing and SIGMA variations. The paths were from the Carolinas, New York, and Colorado areas and consisted of varying interfering geometries.

Results

The predicted C/I values were over-estimated on the average of 4 dB with a standard deviation of approximately 5 dB as compared with the measured C/I values.

Defining Scattering Area

as used in the Comsearch Model



V. Measurement Considerations

The Value of Measured Data

Before considering how measurements can be applied to a scatter problem it is first important to understand the real value of measurement data in general. Measurement data is most useful when used in conjunction with associated engineering calculations or predictions. This is especially true when evaluating the field interference environment. Experience has shown us that combining proper interpretations of both predicted and measured data will result in a higher confidence answer. We have come to rely on measurement data to help validate predictions. While measurements do not always match predictions, they can provide a necessary confidence factor in the existence and magnitude of a problem

The reason for variability between predictions and measurements stems from the complexities of the actual field environment as opposed to the simpler, yet conservative, environment assumed in predictions. Interference predictions typically try to assume the worst case and users allow this conservatism to act as a safety buffer in their analysis. This typically results in measurements that show the interference is less than the predicted value more often than not, especially when over-the-horizon or blockage losses are included. Conversely, measurements are usually performed over a short time period and are, in reality, a snapshot of the interference condition at the time of the test. Over longer periods of time conditions can change, depending on many factors. This is where the burden is placed upon the engineer to interpret and compare both measurements and predictions to arrive at the most realistic conclusion.

Defining the Measurement Goal

The first step in preparing to perform any measurements is to define the goals or objectives of the tests. This is especially true of scatter measurements. What are you attempting to prove or disprove? Are you trying to convince yourself there is no problem or must you convince other coordinators or companies as well? First determine what information it will take to prove or disprove your case. There is usually a lot more involved than simply measuring a receive signal level. You must be sure of the origins of the signals you are measuring, their transmission parameters, the nature of any scattering mechanisms, the nature of any path blockage or other path losses, etc. Simply stated, a good test plan prior to going to the field can eliminate making a second trip.

Defining the Test Plan

You must understand the interference cases in order to prepare a test plan. Measurements usually result from either a problem discovered on an existing path or from the interference analysis of a planned path or upgrade. In either case the first thing to do is run a scatter interference prediction to identify all potential cases.

Remember that anywhere there is a beam intersection between two or more paths there is a chance for terrain scatter interference to occur. Figures 1 through 3 show the three different configurations of beam intersections that can cause scatter interference.

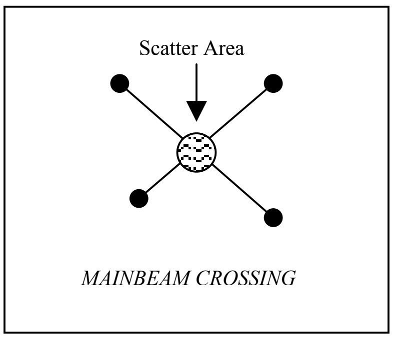


Figure 1

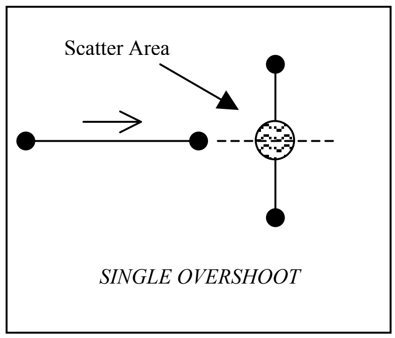


Figure 2

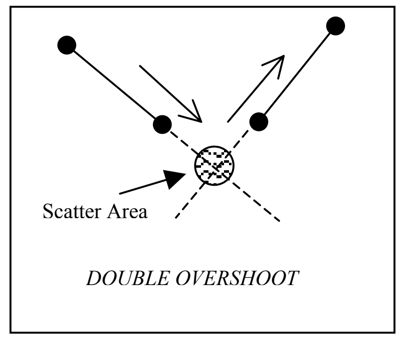


Figure 3

The interference prediction models available identify the paths that intersect with conflicting frequency plans. These programs also have options to consider terrain shadowing to provide a more realistic result.

Once you have reviewed the list of potential cases and selected those needing further investigation the next step is to examine the geometry of the paths in relation to each other. This is best done on a series of topographical maps. The most critical area to review is that surrounding the intersection of the two microwave beams, called the scatter area or "common volume" of the paths. The goal here is to evaluate potentially reflective structures or terrain that would cause the actual scattering of the beams. Structures such as water tanks, radio towers, high power lines, oil wells, and buildings can make excellent scattering mechanisms. Obvious terrain features such as a visible ridge or cliff would also indicate a good source of terrain scatter. Cases meeting these conditions would be good candidates for measurements.

Now you can answer the question, "what cases should I measure?". In general, when two paths have been identified with good confidence as potential victims of scattering interference, measurements should be performed at each of the four sites. At each site the levels of the undesired transmitter should be measure on as many channels as possible.

In "bucking" situations or when the ends of two or more paths are closely located and operated on unmatched frequency plans, the most critical sites to be measured are those outlying stations looking toward the two collocated stations. The reason for this is that the beams from the outlying stations usually have large common volume areas that include both collocated towers, which are good sources of reflection themselves.

Quantifying Interference Levels

Scattering mechanisms are similar to antennas in that they have peaks and nulls at different frequencies. When measuring interference it is important to keep this in mind. Actual field tests have shown up to 15 dB variations in scattered signal strength across a 30 MHz channel at 6 GHz. Optimally, it would be desirable to sweep test somewhere between 10-30 MHz in bandwidth to account for these variations; however, logistics as well as FCC license limitations sometimes preclude this type of testing. In reality, we are sometimes only left with the ability to measure the operating channels signal strength. This is especially true when trying to identify several interference sources into one path. In this situation you may be measuring without the cooperation or knowledge of the second operator. Yet, you still need to quantify the level and identify the source. In this situation it is imperative to be able to measure at least 3-5 channels across the band to help compensate for frequency variations. The worst case level recorded should then be used for interference analysis.

Effects on Polarization and Stability

Scattering mechanisms do not convey the polarization integrity of the scattered signal in many cases. This is dependent upon the scattering surface. A smooth flat and stable surface such as that of a building will produce a constant scatter level and, in most cases, maintains some polarization integrity in the range of 10 to 15 dB or more. This does not always mean the same transmit polarization will be maintained as some skewing has been seen to actually reflect a somewhat reversed polarization of signals. A diffuse scattering surface, such as a hillside full of trees, usually skews polarized signals so there is little (5 to 10 dB) or no distinct polarization advantage at the scatter receive station. Another indication of this type of diffuse scatter mechanism are varying receive signal levels due to the unstable nature of trees and leaves blowing in the wind. It is typical to see variations of 5-10 dB in receive signal strength in these situations.

Verification of the Interference Signal

One of the most important parts of a scatter measurement is the identification of the signal source. In remote areas where there are few paths in the band of concern this is not usually difficult and can be done by matching measured frequency, polarization, and modulation type. In congested areas where there are multiple sources and potential interferers the task becomes more difficult. Obviously, the most positive way to identify a signal is by coordinating a shut down test with the operator. As mentioned previously, this is not always logistically possible or desired.

For example, consider the problem of troubleshooting an existing path in a congested environment where low levels of suspected scatter interference have been discovered. The desired course of action is to track down the source or sources of the problem without coordinating numerous shut-down tests so that time and resources are not wasted. One way to accomplish this is to take a reading of exact carrier frequency and spectrum signature of the interfering signal in the affected receiver. Matching this "spectrum fingerprint" to that of similar isotropic measurements of the suspected transmitter's emissions has been proven to be a highly reliable technique in identifying the correct source. This works very well when measuring analog signals but is more difficult when dealing with broadband symmetrical signals such as digital. In the case of digital signals you must look for anomalies in the spectrum that will differentiate the transmitter from other similar digital signals. Be careful not to confuse the distortion in a digital spectrum shape that is caused by the scatter mechanism with distortion or anomaly from the transmitter. This is not possible in all cases but in many there is enough other corroborating information to identify the right transmitter as the source.

Verification of the Scattering Mechanism

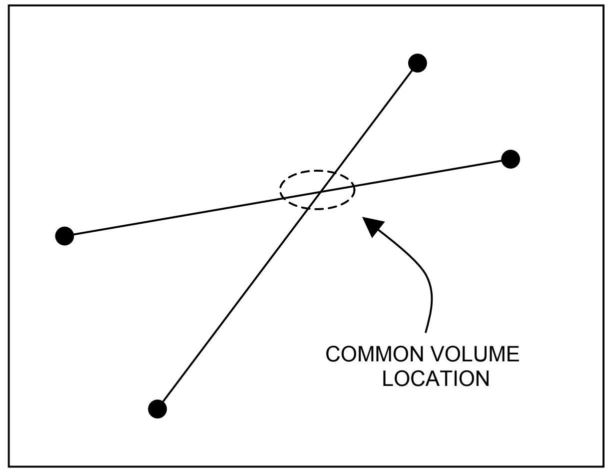
In most cases it is not difficult to identify the scatter mechanism. A review of the obstacles and topography of the common volume area of two paths can usually identify it. Sometimes it can be seen directly from the maps and sometimes it requires a visit to the common volume area to discover the cause of the scatter. Whatever the case may be it is very important to identify the mechanism if you plan to consider solutions to the problem.

Assume for this discussion that frequency engineering or simple options are not available and you must deal with the scatter mechanism to correct a problem. Discreet scatter mechanisms can sometimes be modified or removed to reduce the scattering levels. Small towers or other structures may fit into this category. Terrain scattering, on the other hand, can only be dealt with by changing the terrain features or re-engineering the geometry of the paths to shadow, or provide loss, along the paths to the common volume or scattering area. This can mean minor to major path design changes in order to be effective. In the rare cases where it is very difficult to identify the scatter mechanism it is possible to perform time domain delay measurements similar to the concept of radar to determine the distance from the microwave station to the scattering source.

Beware of atmospheric related anomalies that can cause similar problems. In moisture laden mountain regions where fog tends to build in the valleys when the air cools, you can sometimes see reflective effects from this layering, which may change once the air warms and the fog dissipates. Experience has shown 15 dB changes in some instances.

VI. Avoiding Terrain Scatter (Reflective) Interference

The vast majority of terrain scatter RFI cases involve RF scattering within the "common volume" of the interfering and interfered into antennas.



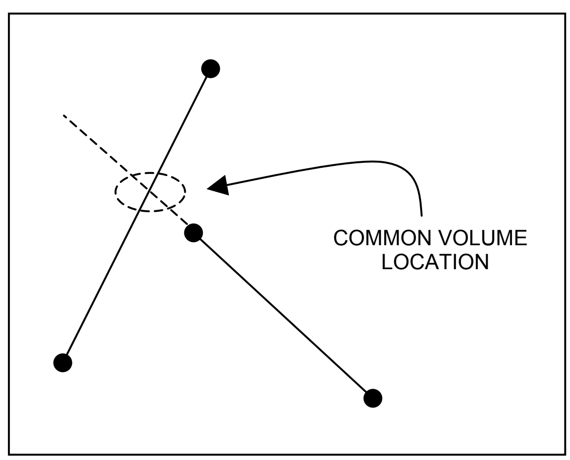
Definition: The "common volume" is that three-dimensional space that is within (i.e., common to) the main beams of the two antennas involved in the RFI case.

To illustrate, we choose discrimination angles that will ensure at least 5 dB of discrimination from boresight using a 10-foot antenna. At 4 GHz this would be ± 2 degrees from boresight; at 6 GHz it would be ± 1 degree.

At 15 miles out on any path the 4 GHz beam width would be one mile wide. The 6 GHz beam width would be 1/2 mile wide. Note: The lengths of the "operating paths" do not affect the size of the common volume. It is a function of only the discrimination and the distance from the two antennas involved in the interference case.

Given two paths that cross at a 90-degree angle, both at their 15-mile points, the total land area within the common volume covers approximately one square mile at 4 GHz and 1/4 square mile at 6 GHz.

In the vertical plane, very little of a microwave path can be disregarded as a potential for scatter interference. Given a 350-foot antenna height and flat land, at 4 GHz the antenna main beam will intercept the ground within two miles of the tower. At 6 GHz the distance is less than four miles from the tower.

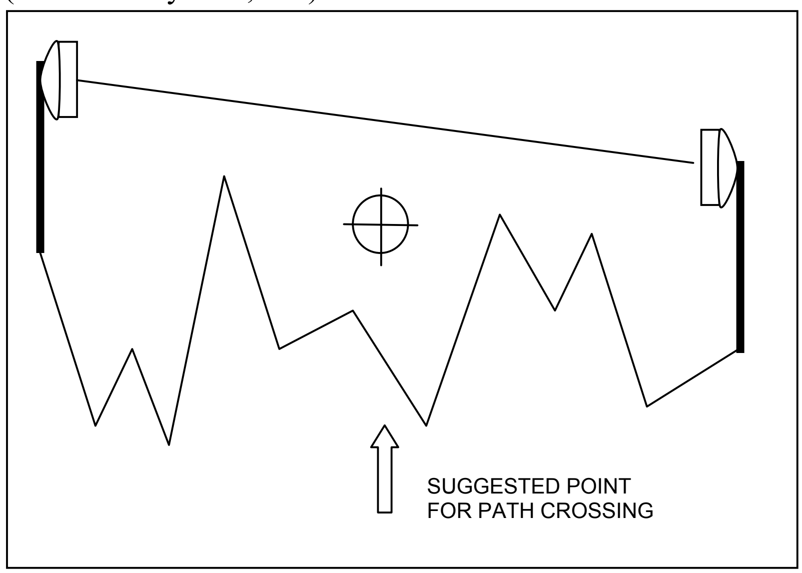


Any two 2-way microwave paths that operate in the same frequency band, and have a common volume, are potentials for scatter interference. The common volume is not necessarily on the paths between the operating antennas. It can be located beyond the receiver on the interfering path, and/or behind the transmitter on the interfered into (i.e., victim) path. It is only necessary for some physical objects (hills, trees, buildings, etc.) to be mutually visible to both the interfering and victim antennas. (See also Figures 1 through 3 on page 10, Section V.)

The best way to avoid terrain scatter RFI is not to build microwave paths in the same frequency band which cross, even within a reasonable distance of the extension of the operating paths. If this were possible, we would never have terrain scatter RFI.

When it is necessary to cross an existing microwave route, the crossing should be located to avoid anything being in the common volume of the two paths involved. This may be impossible if the intersection is in the middle of the two paths, unless the stations are on four mountain top sites.

Sometimes it may be possible, with careful study of the profile of an existing path, to locate a portion of the path that is not visible (shadowed by hills, etc.) from either one or both ends of the path. If the shadowed distance is large enough to contain the four main beams, it may be a workable path crossing. Remember, both ends of the existing path and both ends of the new path are candidates for scatter RFI. Both interference coupling paths must be shielded at some point.

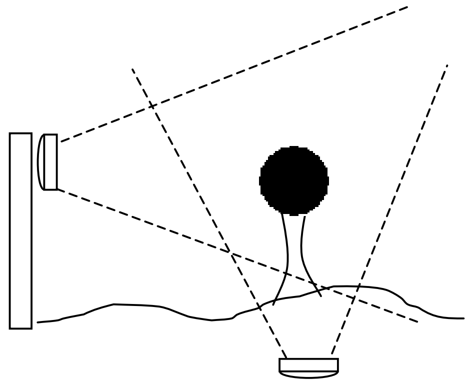


Another solution to terrain scatter is to locate one station of the new crossing path close to one of the existing stations. The transmit-receive frequency pattern of the new station must match (i.e., be the same as the nearby existing station. The requirement then is to set the new antennas high enough so that the main beams would not intercept the ground and any trees or buildings at the path crossing point. Likewise, the main beams of the existing station must also be above any potential scatterer. Of course, the new site must be located so that the microwave towers themselves do not obstruct or scatter any signals.

Similarly, tower guy wires must be avoided. Tower guy wires in a microwave path are notorious for creating both scatter interference and envelope delay distortion. Of course, the line-of-sight interference calculation must meet objectives. This scheme is much like creating a junction station with two separate towers.

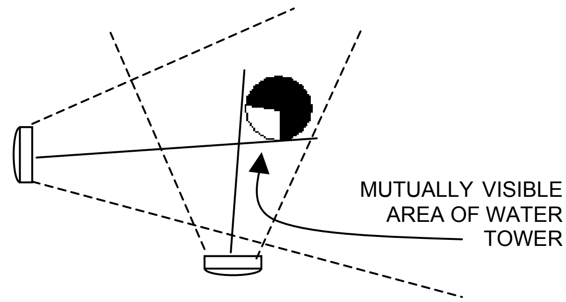
When a path crossing at a potential scattering location cannot be avoided, two schemes can be used to minimize the resulting scatter interference. First, the interfering and the interfered into signals should be cross-polarized. Cross-polarization (cross-pol) usually will reduce any resulting RFI from as little as 5 dB to as much as 20 dB. However, in some instances, this has not proven true. Whatever the case, the first choice is to use cross-pol. If possible, leave open the option for parallel polarization should on-site measurements indicate an improvement.

A second method to reduce scatter RFI is to locate the new sites so as to optimize the angle between the interfering and interfered into paths at the common volume point.



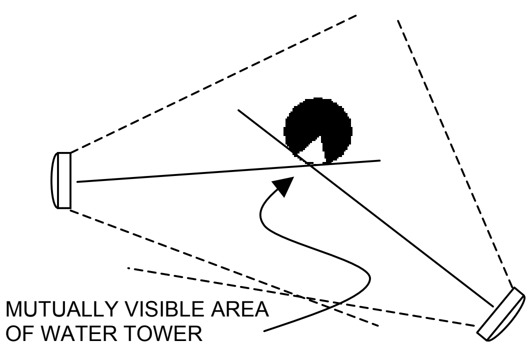
A water tower within the "common volume" of two paths.

To illustrate: given a path crossing with a 90 degree angle, and a round water tower in the common volume, only 1/4 of the water tower is mutually visible to both the interfering and the interfered antennas.



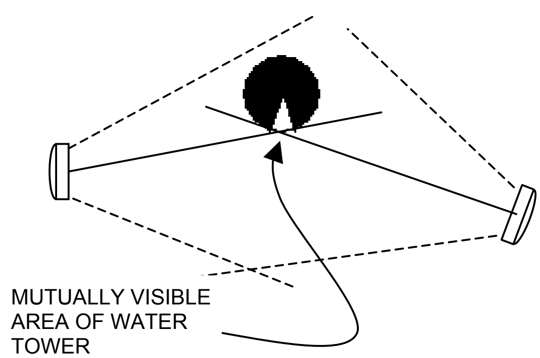
Paths crossing at 90 degree near a water tower.
Approximately 25% of the water tower is mutually visible.

If we relocate the interfering path so the interfering antenna moves away from the interfered into antenna, less and less of the water tower is mutually visible. (See below.)



As the angle at the crossing gets larger, the mutually visible area decreases.

If we go too far, the interfering antenna will be in-line with the water tower and, of course, with the interfered path. We would now have a line-of-sight RFI case. (See figure below.)

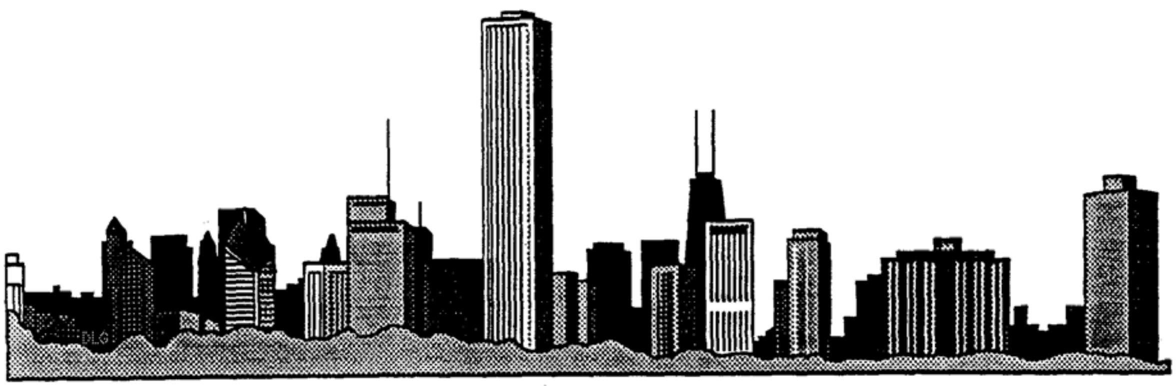


As the angle at the intersection approaches 180 degrees, virtually none of the water tower is mutually visible. However, a line-of-sight case is likely.

The idea here is to cross the existing path at an angle that will minimize the mutually visible areas within the common volume but still comfortably meet the line-of-sight interference computation.

The round water tower is used here only as an example. In real life, anything within the common volume, be it trees, hills, buildings, or whatever, act in much the same way as the hypothetical water tower. As more and more objects or terrain features become mutually visible, the scatter effect gets worse.

The worst scatter or reflected interference results from mixed high/low frequency patterns in cities, that is, some stations transmitting high and others transmitting low frequencies from within the city. The only advice is "match the existing frequency pattern." If sufficient antenna discrimination is not available to match the existing pattern at some azimuth, don't build. If the pattern is already mixed, don't build.



MULTIPLE "BILLBOARD" TYPE SURFACES IN A CITY

Some coordinators have attempted to justify a mixed pattern in a city by measuring the expected RFI at a proposed downtown site. A decision must not be made based just on measurements at sites within the city. The most sever interference from a mixed city pattern is invariable found at the outlying stations. This results from the many large, tall buildings that are obviously within the common volume of any two outlying stations. The buildings act like enormous passive repeaters. In one instance, a 25 dB C/I was measured receiving from downtown Chicago.

Also, due to the multiplicity of potential scattering sources in a city, the measured interference level will not be constant at all frequencies. At one measurement site, a variation of more than 15 dB was recorded across the bandwidth of a single 30 MHz microwave channel. To obtain a legitimate interference reading of any scatter interference case, it is necessary to sweep, at minimum, a 10 MHz bandwidth. Because of the way the power over a bandwidth adds, the peak RFI level must be used for any subsequent calculation.

VII. Examples of Reflection Problems

A number of reflection situations that have been encountered by coordinators and radio engineers have been documented and contributed by members of NSMA in the interest of promoting a better practical understanding of this phenomenon. These are detailed on the following pages.

Situation 1:
Sutherland – Fort Morgan
Ogallala – Julesburg
Roscoe – Chappell

Situation 2:
Latrobe –Laurel
Arona – Waterford

Situation 3:
Earlimart – Cawelo
Famoso – Tipton

Dallas FIB – Ft.Worth Junction

Maywood – Stilesville
Coatesville – Morresville

Norfolk – Benns Church
Carrollton – Norfolk

Mobile, Alabama

Omaha – Kansas City
Liberty – Kansas City

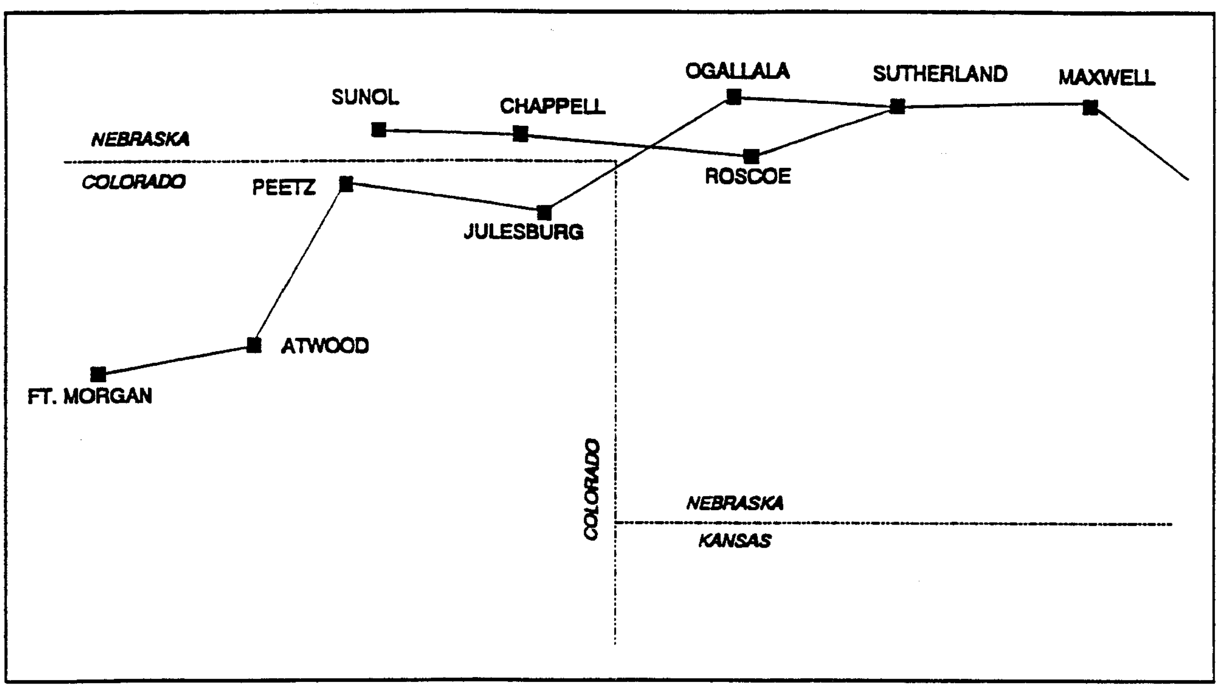
Editorial note: Documentation for the first three terrain scatter situations in the list above is included in this reprinted edition of the tutorial. Documentation for the other situations is not available at this time.

dlg 1/31/05

TERRAIN SCATTER INTERFERENCE
A DISASTER STORY

Situation 1

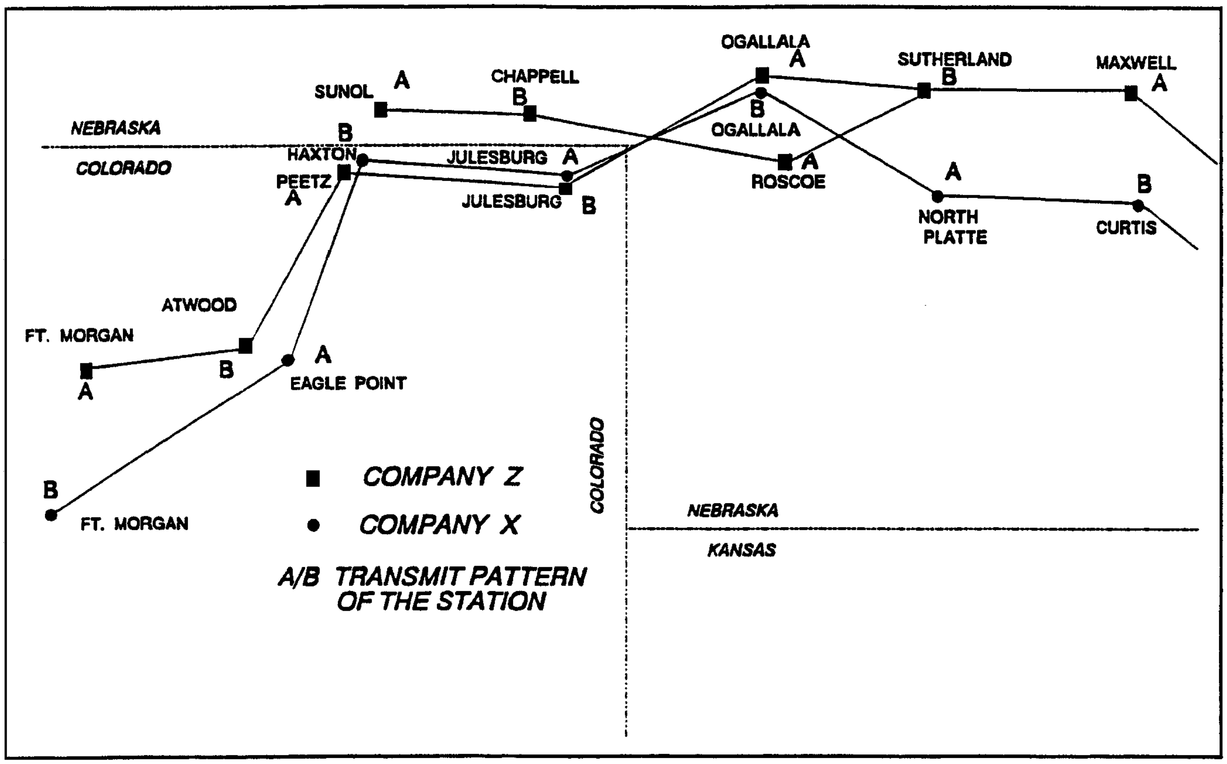
Company Z built the Sutherland, NE - Fort Morgan, CO section of their North Bend, NE – Denver, CO 4 GHz radio route circa 1951. The Sutherland – Roscoe – Chappell – Sunol system was added in 1967.



Initial Company Z System Route Map

(Story continues on next two pages.)

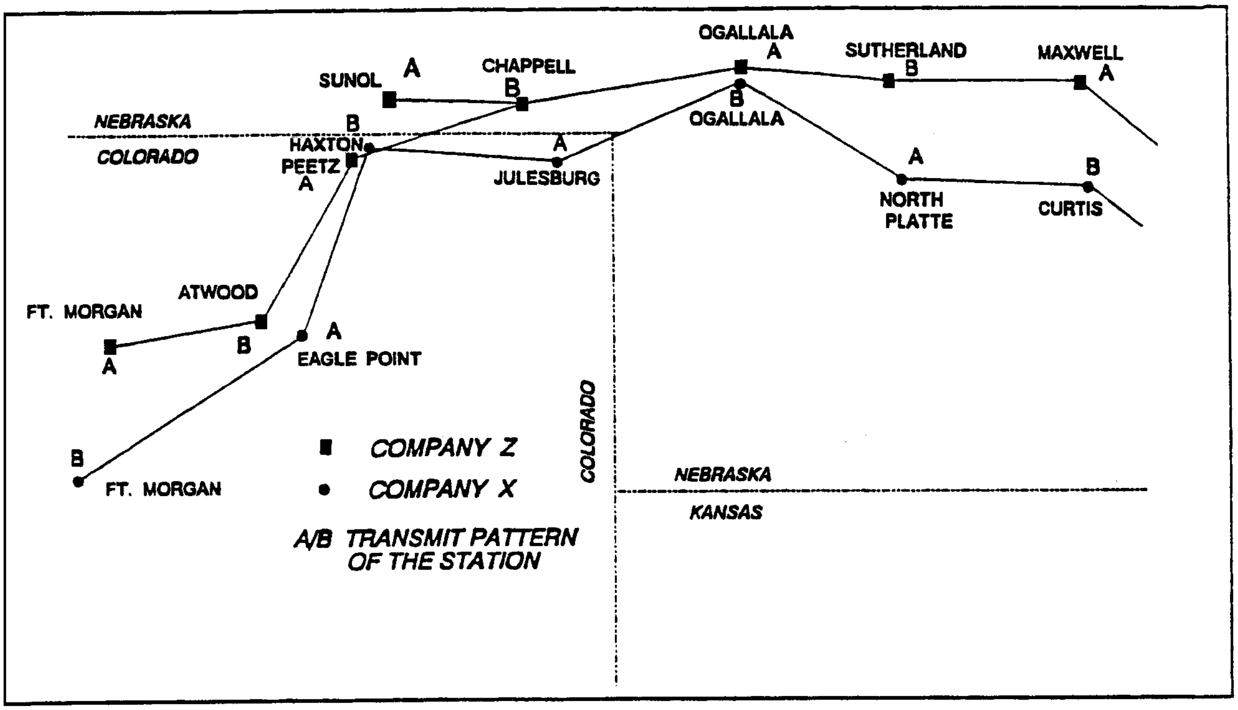
When Company X built their Omaha – Denver system through the area they followed the existing route and located a number of stations within a few miles of the existing towers, among them, Ogallala, Julesburg, and Peetz. Using a frequency pattern opposite of the existing system, Company X was able to coordinate their channels with the Company Z system on a line-of-sight basis. Interference from scattering in rural areas was not known as a problem at that time.



Even after the Company X system was turned up, the interference from scattering was not evident due to the light (600 circuit) analog traffic loading on the Company Z system. Through the years, as circuit requirements increased, technological improvements led to first 1200 circuit loading and then 1500 and 1800 circuit loads on each channel. As a result, the interference became more and more objectionable.

Company Z determined that a barn near the intersection of the two Ogallala – Julesburg paths was of the proper size and orientation to possible cause a reflection. The barn was purchased and then dismantled. Unfortunately, the removal of the barn had little effect on the interference.

Company Z finally decided to abandon their repeater stations at both Roscoe, NE and Julesburg, CO are reroute all service through the station at Chappell, NE.



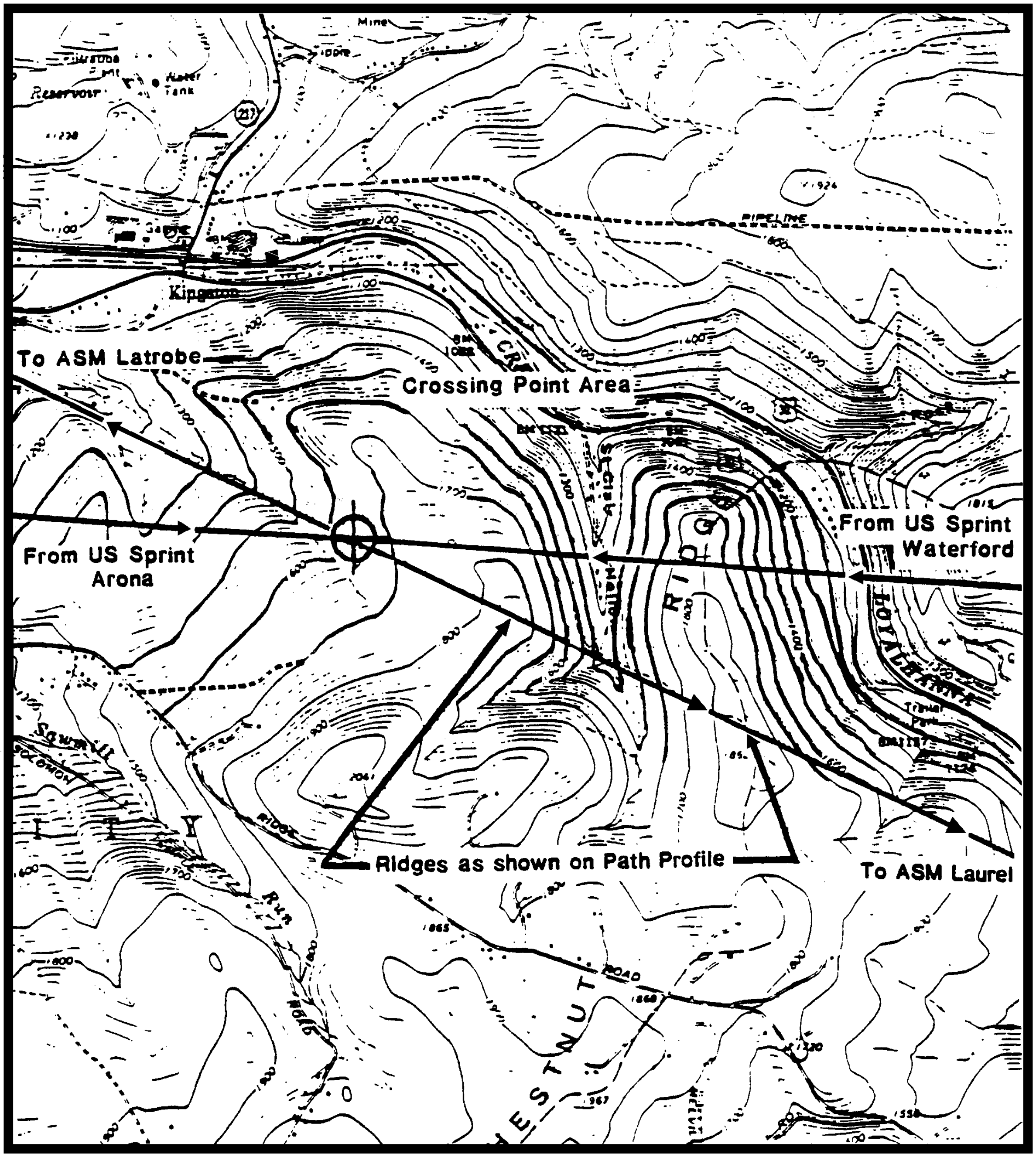
Two new paths were established, Ogallala – Chappell and Chappell – Peetz. This eliminated the worst interference but created a new case at the Peetz tower. The most severe interference is into the Peetz receivers from Chappell and it comes from the transmitters at Haxton toward Julesburg. The case is probably aggravated by the short distance from both stations to the paths' intersection and the narrow angle between the two paths at the intersection.

The interference at Peetz was not severe enough to wipe out Company Z's analog service; however, it did affect a new 90 Mb/s digital service that was turned up later.

We can not explain why this interference case did not turn up in the 90 Mb/s route qualification tests. Whatever the scenario, the 90 Mb/s route was built and the reliability was unacceptable. The interference was so severe that the only solution was to relocate one of the stations. Both companies shared the cost of relocating the Haxton station.

One of the difficulties in analyzing and solving this interference case was the changing C/I levels measured during different times of the year. It appears that a field of fully-grown wheat is about 12 dB more reflective than the bare ground on which it grows.

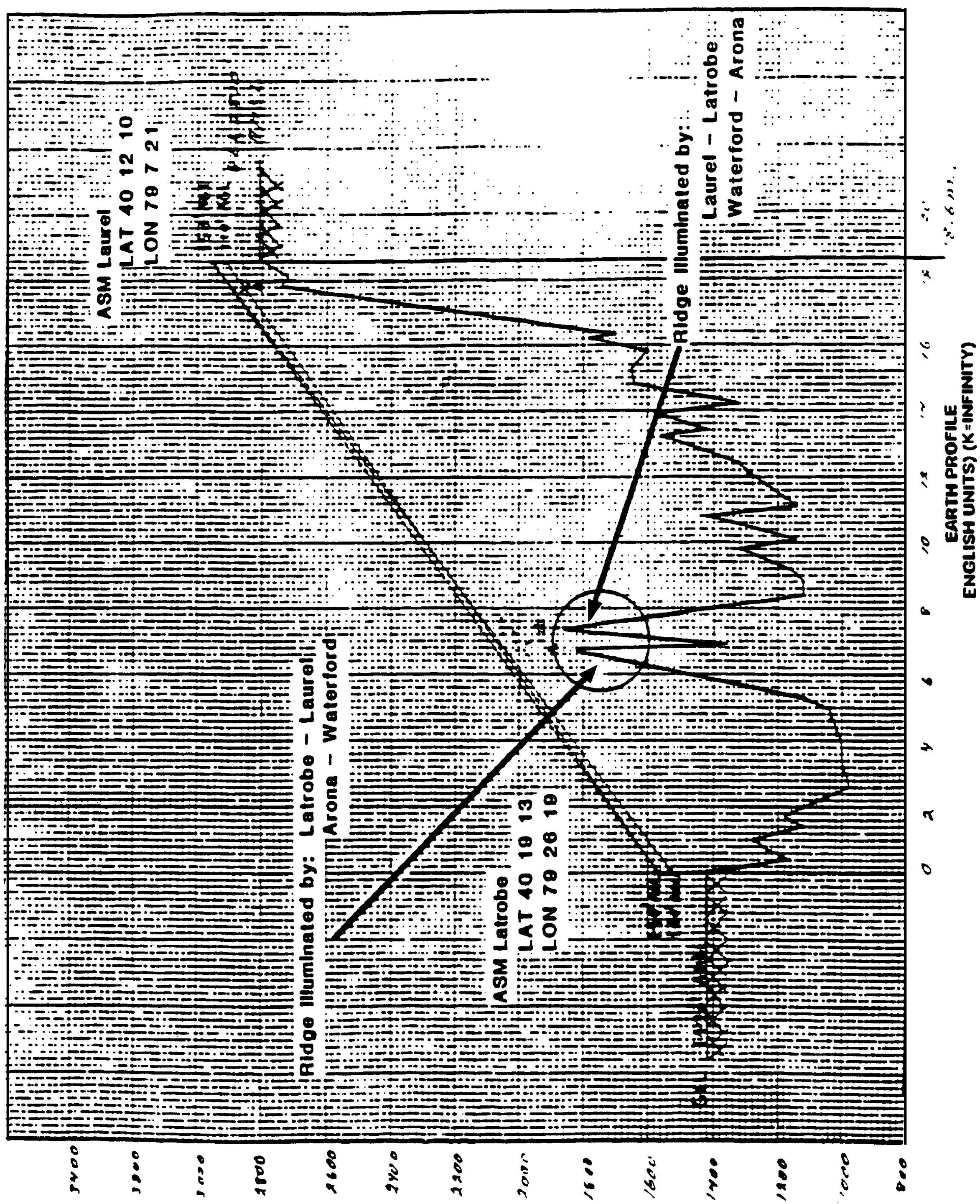
Situation 2



Crossing Point of Latrobe – Laurel and Arona -- Waterford

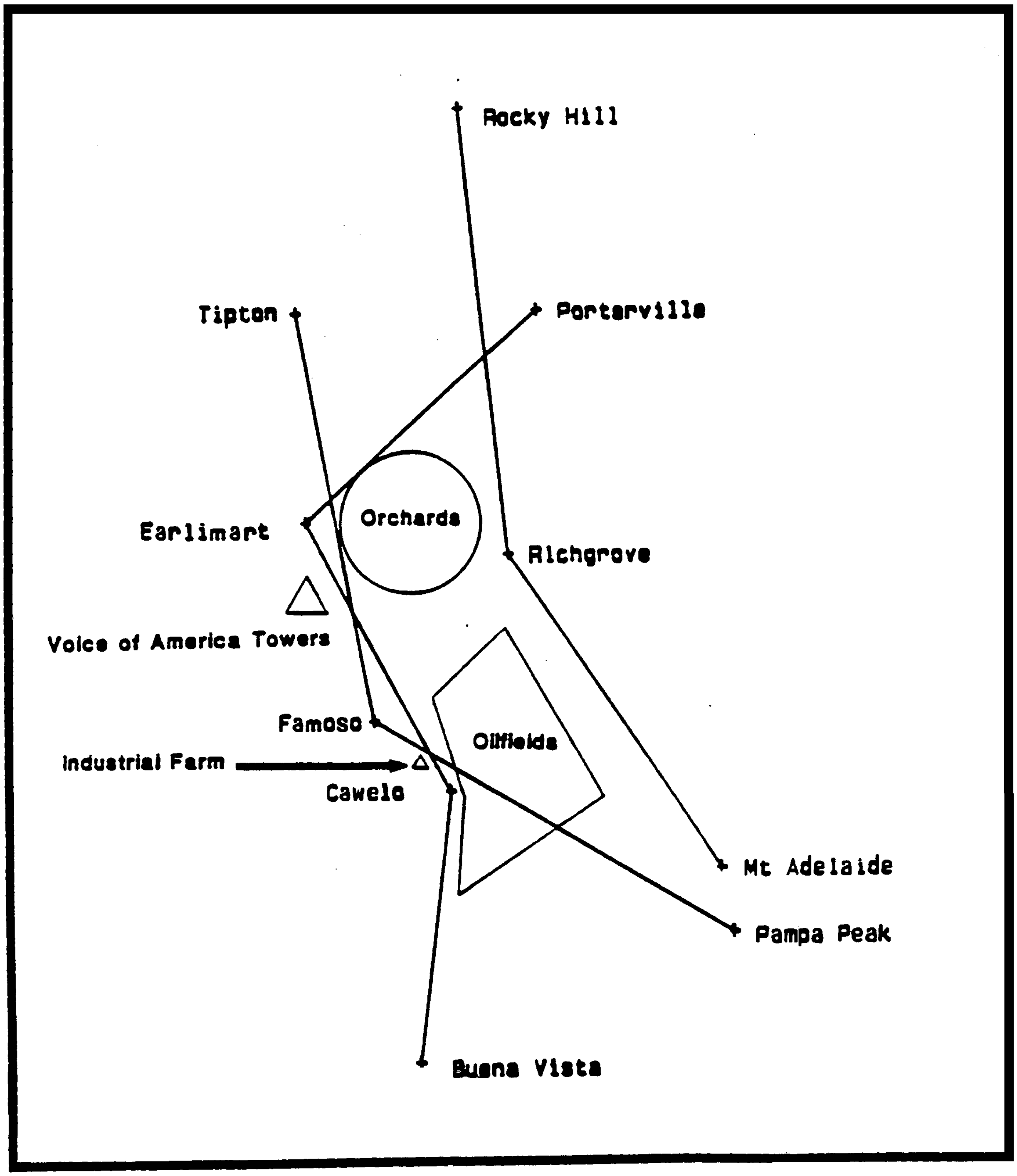
Topographical map above shows the terrain features that are in the common volume of the two crossing microwave paths. The path profile on the following page illustrates the areas that are illuminated by the microwave radio signals from the respective crossing paths.

Situation 2



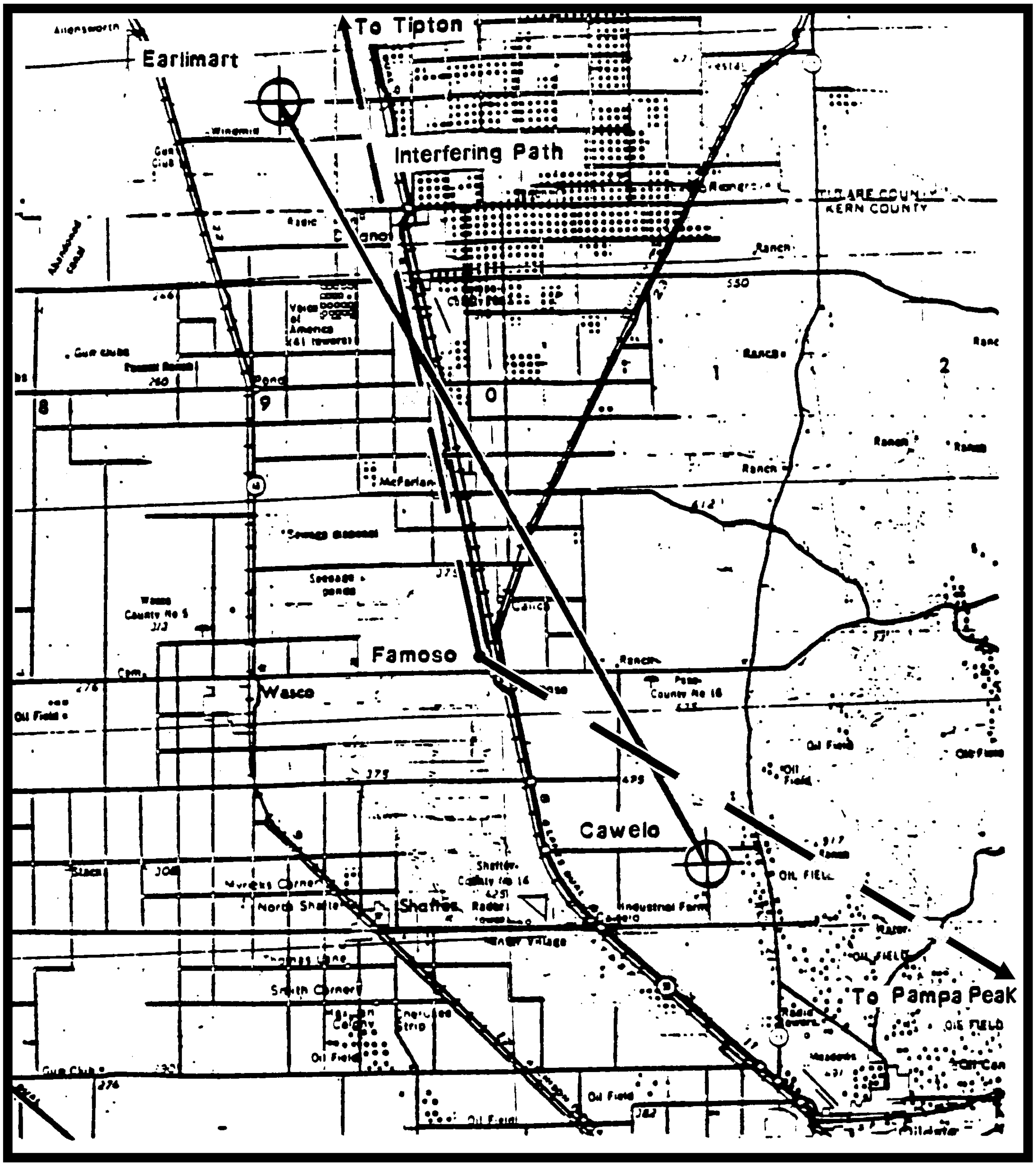
Path Profile of ASM Latrobe -- Laurel

Situation 3



Overview of Crossing Microwave Routes

Situation 3



Earlimart – Cawelo Microwave Path

<u>Situation 3</u>

Earlimart – Cawelo

Problem Path: US Sprint Famoso – Pampa Peak

Victim Receiver: Cawelo

Interfering Transmitter: Famoso

Probability for Terrain Scatter: High

Description: US Sprint runs 2400 channel message along this path. The oil field north of Cawelo has a strong potential to provide reflective surfaces which can cause interference into Cawelo. This is due to the number of oil storage tanks in that area and their large surface area.

Problem Path: US Sprint Famoso – Tipton

Victim Receiver: Cawelo

Interfering Transmitter: Famoso

Probability for Terrain Scatter: High

Description: US Sprint runs 2400 channel message along this path. The Voice of America radio towers are located in proximity to the US Sprint path. Since there are 41 towers in the antenna array, the possibility of reflective interference exists.

Problem Path: US Sprint Tipton – Famoso

Victim Receiver: Earlimart

Interfering Transmitter: Tipton

Probability for Terrain Scatter: Medium

Description: US Sprint runs 2400 channel message along this path. The Voice of America radio towers are located in proximity to the US Sprint path. Since there are 41 towers in the antenna array, the possibility of reflective interference exists.

VIII. Glossary of Radio Terms

ABSORPTION	During propagation of microwave radio signal, some radio energy is absorbed by the atmosphere.
ABSORPTION FADING	Absorption fading at microwave frequencies is caused by precipitation absorption and scatter. Absorption fading increases as the signal wavelength approaches the diameter of the raindrops.
ANGLE DIVERSITY	See "DIVERSITY, ANGLE."
ANGLE OF INCIDENCE	Angle at which a radio or light beam hits a reflector. It is measured from the normal or perpendicular to the surface.
ANGLE OF REFLECTION	Angle formed by the radio or light beam reflecting from the surface and equals the angle of incidence.
ANTENNA	A device for radiating electromagnetic radio waves into space or for receiving radio waves from space.
ANTENNA BANDWIDTH	The range of frequencies that an antenna will effectively transmit and receive.
ANTENNA BEAMWIDTH	The angle between the directions on either side of the center axis of highest gain of the antenna radiation pattern where the field intensity is 3 dB less than the maximum value. Beamwidth is generally specified for the horizontal plane deviations from the center axis; *e.g.,* ± 1.8 degrees.
ANTENNA DISCRIMINATION	The gain of an antenna in various directions referenced to its maximum gain. Antenna discrimination is reported in the form of a graph (pattern) showing the gain (or loss) of the device in degrees from the center of the main lobe (direction of highest gain) in the horizontal plane and sometimes in the vertical plane. It is important to note that these patterns are produced on an antenna measurement range under very controlled conditions. Antenna discrimination may change when an antenna is installed in different surroundings. Antenna discrimination is usually referred to as a positive number (of dB), representing the difference between the gain at a particular angle and the maximum gain (*e.g.*, 25 dB discrimination at 22 degrees). See "DISCRIMINATION ANGLE."

BUCKING	"Bucking" is defined as a mixed high/low transmit frequency pattern (and corresponding low/high receive pattern) at either an individual remote repeater station or among several terminal stations within a city. (See Section III for a more complete discussion.)
COMMON VOLUME	Common surface area within the 3 dB beamwidth of the interfering and interfered with antennas at the intersection of two microwave radio paths.
DIFFRACTION	The principle which allows electromagnetic waves to bend around obstacles and partially fill the area behind the obstruction. The diffracted wave is projected into the geometrical shadow region.
DIRECT WAVE	A wave that is propagated directly through space from transmitter to receiver.
DIRECTIONAL ANTENNA	An antenna that radiates or receives radio waves primarily in one direction.
DISCRIMINATION ANGLE	The angle between the center of the main beam of one station's antenna and the path from that antenna to another station's antenna (usually a potentially interfering station). The sensitivity of an antenna changes, or "discriminates", against other signals arriving off the main beam of the antenna. Among terrestrial stations, this is more or less a horizontal angle. See "ANTENNA DISCRIMINATION" and, regarding satellites, see "SLANT ANGLE."
DISPERSION	The scattering of a radio signal as the result of an obstruction in the radiating path.
DISTORTION	Difference in the output waveform as compared to the input waveform. Distortion may consist of irregularities in amplitude, frequency, or phase.
DISTORTION DELAY	Defined in terms of the delay at one frequency relative to that of another. The reference frequency may be taken as the frequency of minimum delay.
DIVERSITY	The provision of an additional path or paths through which a desired signal may travel. In microwave systems, this is accomplished by providing a backup system on another frequency (frequency diversity) or an additional antenna and receiver at each end of the path (space diversity) or

with a dual feed antenna (angle diversity). The backup frequency diversity system is automatically switched on line when the signal from a protected system is lost. Typically a single backup system protects a number of working systems (1:n protection: read as "one for n protection"). Space diversity and angle diversity receivers are either switched in to replace the single system they protect or the diversity signal is continually combined with the primary signal.

DIVERSITY, ANGLE — The use of a single antenna with two slightly displaced feeds that provides separate outputs as if from two antennas with different vertical patterns. Because the patterns are different, multipath rays are unlikely to cause the same amount of signal loss in both feeds simultaneously.

DIVERSITY, FREQUENCY — Protection against equipment and propagation failure to a working radio channel by providing a second radio channel spaced as far away in the frequency as the circumstance of channel selection permits. Frequency diversity takes advantage of the different wavelength of the two signals and the tendency of two such different wavelengths to be affected differently (or selectively) under multipath fading conditions.

DIVERSITY, SPACE — Form of diversity transmission or reception which uses a second antenna, usually placed vertically above or below the primary antenna (usually the main receiving antenna). A diversity receiving antenna reduces the overall probability of propagation outages significantly.

DOUBLE DIFFRACTION — A radio path with two obstructions, each of which causes beam bending in sequence.

DUCTING — Propagation condition that results from varying density layers in the atmosphere that redirects the travel of the signal by refraction. The trapping of a radio wave between two dense atmospheric layers. The wave cannot escape because it is refracted back and forth each time it reaches the denser layers.

EARTH FLATTENING — The label applied to propagation conditions where the K factor becomes greater than the normal 4/3 value.

EARTH STATION	A ground station that has been designed and built to communicate with an orbiting satellite. Earth stations normally transmit at higher frequencies than they receive. Typical pairs of transmit/receive frequencies include 6/4 GHz, 14/12 GHz, 14/11 GHz, 17/12 GHz, 13/10 GHz, and 30/20 GHz. Most earth stations used for video distribution are receive only.
FADE MARGIN	The fade margin of a receiver is the difference (in dB) between the nominal receive signal level (RSL) and the threshold RSL.
FADING	The variations of radio field strength due to changes in the transmission medium (atmosphere).
FREE SPACE LOSS	The radio path loss resulting from the unobstructed transmission, *i.e.*, dispersion, of a radio signal when it leaves an antenna. It can be computed from the following equation: FSL = 96.6 + 20 log D + 20 log F (where D is in miles and F is in GHz).
FREQUENCY	The number of repetitions of a periodically recurring waveform per second, usually expressed in Hertz (Hz), kilohertz (kHz), Megahertz (MHz), or Gigahertz (GHz).
FREQUENCY DIVERSITY	See "DIVERSITY, FREQUENCY."
FRESNEL ZONE CLEARANCE	The vertical or horizontal distance measure from the center of the radio beam to the top or side of the particular obstruction in terms of the additional length of this path (transmitter to obstruction to receiver) in terms of half wavelengths. The first Fresnel zone boundary is an ellipsoid with its surface made up of the locus of points such that the distance from transmitter to a point to receiver is one half wavelength longer than the direct path between transmitter and receiver. The second Fresnel zone boundary relates to a distance of two half wavelengths longer, and so on.
HORIZONTAL POLARIZATION	Orientation of a polarized electromagnetic wave whose electric field is horizontal with respect to the earth's surface.

INTERSECTION	The crossing of two radio beams, as between earth station and terrestrial station beams or the crossing of the radio beams of two terrestrial stations, each associated with different paths.
INTERSYSTEM INTERFERENCE	Radio frequency interference (RFI) from one microwave radio system into another system.
INTRASYSTEM INTERFERENCE	Radio frequency interference (RFI) between stations of the same microwave radio route.
ISOTROPIC ANTENNA	An antenna which radiates equally in all directions.
JUNCTION	A radio station with 3 or more paths radiating from it.
K FACTOR	That fraction or decimal used to indicate the ratio between the apparent earth radius and the true earth radius. It is a measure of the amount of radio beam bending due to atmospheric conditions. It is the factor by which the actual earth radius would have to be multiplied in order to have the same curvature as the radio beam.
LONG HAUL	Used to designate a type of radio route so as to establish the criteria by which it will be engineered. Usually a 4000-mile analog route in which a total of 41 dBrnC0 of noise is allowed.
LONG TERM	The radio interference path loss that will be exceeded a certain percent of the time. The notation is L80, for example, for 80 percent of the time.
MICROWAVE	Radio transmission using wavelengths of 30 centimeters or less, which exhibit some of the properties of light. Microwaves are used in point-to-point communications because they are easily focused into a beam by parabolic antennas.
MODULATION	The process in which the amplitude, frequency or phase of the radio frequency carrier wave is varied with time in order to carry information on the signal.
OBJECTIVE MARGIN	That measure in dB that the objectives have been exceeded (+) or missed (-).

OBJECTIVE	That carrier-to-interference (C/I) ratio in dB between the wanted and the interfering signal that should be strived for in order to not violate the permissible interference level.
OMNI-DIRECTIONAL	In all directions – as a radar station that radiates in all directions, even if not simultaneously.
ORBITAL INTERSECTION	The intersection of a terrestrial station radio beam with satellites in the geostationary orbit above the equator.
ORTHOGONAL	Perpendicular to each other.
PARABOLIC ANTENNA	A curved "dish" shaped antenna. It is constructed so that all waves intercepted will be reflected in phase to a common focal point. A concentrated narrow beam of energy results when this type of antenna is used to transmit.
PROPAGATION	The traveling of electromagnetic waves or sound waves through a medium.
PROPAGATION OUTAGE	A complete loss of the desired radio signal due to multipath or obstruction fading.
pW	Abbreviation for a picowatt—equals 10^{-12} watts, -90 dBm, and –120 dBW. A unit of absolute power used for both weighted and unweighted noise.
RADIATION PATTERN ENVELOPE	Diagram indicating the gain (or loss) of an antenna in degrees from the center of the main lobe, usually in the horizontal plane; sometimes in the vertical plane. (Abbreviated as RPE.)
RADIO HOP	The propagation link or path from antenna to antenna.
RADIO WAVE	A radio wave represents electrical energy that has escaped into free space. A radio wave travels with the velocity of light and consists of magnetic and electric fields at right angles to each other and also at right angles to the direction of travel.
RECEIVED SIGNAL LEVEL (RSL) RECEIVER INPUT LEVEL (RIL)	The signal strength in dBm at the input of a receiver, before any amplification of the desired signal, obtained by combining all gains and losses over a radio path. (See equation below.)

$$RSL = P_T - W_{GT} + G_T - FSL + G_R - W_{GR}$$

where:

P_T = transmitter power
W_{GT} = transmit-end wave guide loss
G_T = transmit antenna gain
W_{GR} = receive-end wave guide loss
G_R = receive
FSL = free space loss

REFLECTION — The redirection of a wave with the angles of incidence and reflection being equal and in the same plane.

REFLECTION COEFFICIENT — The ratio "r" of the electric field strength of the reflected wave to the strength of the incident wave.

a. A pure reflector absorbs no energy; therefore r = 1.
b. A non-reflecting surface absorbs all incident energy, therefore r = 0.

REFRACTION — A phenomenon which causes the direction of an electro-magnetic wave to change due to a difference of velocity from one medium to another.

REGENERATION — The process of reconstructing distorted pulses in a digital radio signal.

RFI — Radio frequency interference.

SCATTERING — The dispersion of radio frequency energy when it comes in contact with uneven surfaces or atmospheric particles. Scattering effects are frequency dependent and are a function of the wavelengths and the roughness of the surface or size of the particles.

SELECTIVITY — Degree to which a radio receiver can accept the signals of one desired station while rejecting those of all other stations on adjacent channels.

SENSITIVITY — The minimum input signal required to produce a specified output signal having a specified signal-to-noise ratio.

SHADOW LOSS — A term used to refer to the loss of a radio path with a single obstruction very close to one of the stations.

SHORT HAUL RADIO — Usually a radio route with a maximum length of 250 miles. The maximum noise objective per hop of analog radio is 22 dBmrC0 which assumes 10 hops for a total of 32 dBrnC0 for the route. Used for end links only, no through circuits or trunks allowed.

SIDE LEG	A radio leg or spur that branches from a route.
SIGNAL-TO-NOISE (S/N)	Ratio of the magnitude of the signal to that of the noise, often expressed in decibels (dB). The signal is defined as the value of the transmission level point (TLP) signal level minus the noise level in dB.
SITE SHIELDING	A natural or devised obstruction around a radio or satellite site that serves to shield the station from radio signals or to reduce their transmission in certain directions.
SKY WAVES	Energy that is propagated in the space above the earth under conditions affected by the ionosphere. The variation in the height of the ionosphere and the resultant variation of the point at which the reflected sky wave arrives accounts for the variation in signal intensity between day and night, winter and summer, etc., in long distance signals.
SLOPE	The difference in attenuation or insertion loss at two different frequencies or within the frequency band.
SLANT ANGLE	That angle that is described by an earth station looking at a satellite with the path from the earth station to a terrestrial station. It is the combination of both a vertical and a horizontal angle. Between a terrestrial station and satellite, the terrestrial station discrimination angle is the angle between the main beam of the terrestrial station and the path to the satellite. Similarly, between an earth station and a terrestrial station, the earth station discrimination angle is the angle between the earth station's main beam and the path to the terrestrial station. See "DISCRIMINATION ANGLE" and "ANTENNA DISCRIMINATION."
SPACE DIVERSITY	See "DIVERSITY, SPACE."
SPACE WAVE	The rays traveling directly from transmitting to receiving antenna. Space waves represent the principal means by which energy reaches a receiving antenna above 30 MHz.
STRATA	Layers having identifiable common properties, such as layers of the atmosphere.
THRESHOLD	In a radio receiver, it is the point where the signal power presented to the receiver just equals the thermal noise

power presented to the receiver plus its own internally generated noise.

THRESHOLD BER	The receive signal level in a digital system which produces a certain bit error rate (BER). A BER of 10^{-3} is normally used for engineering calculations.
TRANSIENT	Instantaneous surge of voltage or current which occurs in a system owing to a sudden change in conditions and which persists for a relatively short time after the change has occurred.
TRANSPONDER	In satellite communications, the equipment used to receive in one frequency band and then to amplify, translate in frequency and retransmit in a corresponding segment of a lower frequency band. Most transponders are 36 MHz wide with a 2 MHz guard band on each side. The INTELSAT satellites have transponder bandwidths of 36 MHz, 54 MHz, and 241 MHz. There are at least 71 other transponder bandwidths ranging from 24 MHz to 700 MHz with a 72 MHz bandwidth being used extensively in the C-band.
TROPO LOSS	The path loss that results from an interfering radio wave being reflected from a tropospheric layer to a receiver.
TROPOSPHERE	The troposphere is the portion of the earth's atmosphere, some ten miles thick, immediately adjacent to the earth's surface.
UNIVERSAL GAIN CURVE	The discrimination pattern of very large antennas. It is only valid between 1 degree and 48 degrees from the main beam.
UPSTREAM	Describes transmission phenomena relative to some reference point in a transmission path. Points upstream are those from which signals are being received at the reference point.
VERTICAL POLARIZATION	Orientation of a polarized electromagnetic wave whose electric field is vertical with respect to the earth's surfacae.
WAVELENGTH	The distance traveled in one period or cycle by a periodic disturbance. The wavelength of a signal is the velocity of propagation divided by the frequency.

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