THE FIGURE OF MERIT APPROACH TO SIZING LARGE DOMSATS

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ABSTRACT

A classical problem for the large domestic satellite system planner is the overall mix of types of earth stations that can be utilized in the 4 and 6 GHz bands. Because of overlapping frequency bands with the common carrier terrestrial microwave plant, earth station placement can be extremely difficult. Thus, the planner is faced with major cost unknowns in deciding how many earth stations will colocate next to existing facilities and how many will need to be placed at a remote location and linked to existing facilities via terrestrial microwave and/or cable.

An attempt to analyze each site on an individual basis results in a large computer printout of each site with multiple potential great circle interference cases and beam intersections. Thus, for a large number of earth station locations, the sheer volume of data becomes overwhelming.

Spectrum Analysis and Frequency Engineering (SAFE) has defined and successfully used a Figure-of-Merit to solve this problem. This paper is an in-depth discussion of the Figure-of-Merit approach.

INTRODUCTION

The sharing of the 4 and 6 GHz common carrier frequency bands between terrestrial microwave and satellite earth station facilities dictates a degree of coordination and caution in selecting sites and installing new equipment of either type. And while the current degree of controversy exists regarding the coordination of receive-only satellite earth stations, the potential for interference of one system into the other cannot be denied. The controversy then centers only upon what legal procedural steps will be taken as part of the coordination process.

To assist potential satellite earth station or terrestrial microwave users to find and coordinate equipment sites is one of the charters of the frequency coordination firms. Their standard approach is to maintain a data base of existing and planned facilities. Upon definition of a potential site using latitude and longitude, this data base can be "culled" or scanned to identify all systems operating or planned within a coordination contour surrounding the potential new site. In each case, the degree of direct or "great circle" and "precipitation scatter" interference levels among the systems thus identified is calculated and shown on a tabular listing. By comparing these calculated interference levels to a set of interference objectives, the degree of shielding or other loss-required is identified, which will allow transmissions from each surrounding facility to allow the new installation to operate with the assurance that interference will be below acceptable levels.

In the course of this analysis, it is not uncommon to generate a computer printout fifty pages thick for each potential site.

The planner of a domestic satellite system will often represent an organization which (1) has numerous existing facilities, perhaps many hundreds or thousands, to which information is to be relayed via satellite, (2) requires the most accurate information regarding cost which can be obtained regarding satellite communication hardware to assess the economic viability of the project with respect to the particular circumstances, and (3) requires meaningful ways to "break out" those blocks of the proposed system which can be done on an incremental basis to reduce the overall program risk.

In order for the planner to assess fifty pages of printout for each proposed site, and alternate sites for those with excessive interference levels, for several hundred or several thousand sites, and produce meaningful summary information to higher management in a reasonable amount of time would be almost impossible using standard coordination procedures.

To solve the problem, Spectrum Analysis and Frequency Engineering (SAFE), a business area of Rockwell International Incorporated, developed a Figure-of-Merit (FOM) which would allow the analysis of each potential earth station site to be distilled into a single number for the initial planning stages of a domestic satellite program. Thus the planner could then be given one of four categories representing the range of the FOM.

By being able to quickly identify which of the existing properties were useable, a quantity of "rubber stamp" sites could be identified as the logical first phase of a program. Scheduling and cost analysis of these sites then follows easily. The other three categories produce similar planning guidelines.

In this paper, the Figure-of-Merit approach is discussed, and the application to the now operational Public Broadcasting System Satellite Interconnect System and the proposed National Public Radio and Holiday Inn Systems are reviewed.

THE FIGURE OF MERIT

Two basic definitions are required to build the basis for understanding of the Figure-of-Merit approach, namely (1) great circle interference, and (2) precipitation scatter interference.

Great circle interference occurs when an interference signal propagates over the surface of the earth or via direct line of sight paths into the main beam or sidelobe of the antenna of a receiving station.

Precipitation scatter interference occurs when (1) the main beams of two stations intersect, and (2) particle matter such as rain or snow in the common volume of the beam intersection causes a transmission from one to reflect into the receiving antenna of the other.

For the analysis of a given site, the geodetic coordinates (latitude and longitude) of a desired earth station site are input to the computer. A computer cull of the data base identifies those terrestrial facilities within a pre-determined "coordination contour" Interference objectives are input to the computer. Interference levels at each receiver are made by the computer and compared to the interference objectives. The difference represents a "loss-required" that will necessarily be derived from terrain features, buildings, or other shielding.

The computer calculates a loss-required between the proposed earth station site and every surrounding terrestrial facility, for each great circle case, and a precipitation scatter loss-required or margin, for each beam intersection. When one considers the nature of the precipitation scatter interference, it becomes apparent that, with the exception of waveguide loss in the receiving station, there is no way to shield against it.

From the preceding discussion then, it becomes apparent that the desirability of a proposed earth station site becomes a function of three variables predominately; (1) the number of great circle interference cases, (2) the amount of loss-required on the great circle cases, and (3) the number of precipitation scatter interference cases which have negative margins, or exceed the predetermined interference objectives.

In order to consolidate the great circle cases, the first key assumption is that azimuth is not normally a crucial factor. The horizon gain of an antenna normally varies from +5 db on the azimuth of the main lobe to -10 db at the side or back of the antenna. Thus over a 360 degree azimuth range, the earth station discrimination range is at least 15 db. However, 15 db of shielding can often be obtained by judicious earth station placement or the use of small shrubs or trees for shielding a critical azimuth.

By treating all great circle cases as differing only by the amount of loss-required, and ignoring their azimuth around the planned earth station location, a histogram can be constructed which relates great circle loss-required to frequency of occurrence. A sampling of that histogram at three percentile points then provides a representative assessment of the amount of great circle interference seen by the planned earth station location.

Subsequently, the Figure-of-Merit is defined as follows:

$$FOM = a_1 X_1 + a_2 X_2 + a_3 X_3 + b Y$$

The X values represent the great circle loss-required values at the samples taken at three percentile points on the histogram. The Y value represents the number of negative margin precipitation scatter cases, and the a and b coefficients are based on empirical data from hundreds of earth station sites coordinated by SAFE in previous years.

In order to make the FOM usable, four categories have been defined as follows:

RANGE	CATEGORY	MEANING
$FOM < 150$	OK	Site has at most one critical potential interference source which could be blocked by existing buildings or the addition of trees or shrubs.
$150 \leq FOM \leq 300$	INSPECT	Site has two or three critical potential interference sources, and levels are such that a review of terrain maps should be made to assess the amount of terrain shielding before declaring the site OK.
$300 < FOM \leq 500$	MEASURE	Site has enough potential interference that on-site Radio Frequency Interference (RFI) measurements will be required.
$FOM > 500$	MOVE	Site has unacceptable levels of interference, and another site should be selected.

Previous use of the Figure-of-Merit established it as a conservative model which correctly identified OK sites with a 95% or better confidence level. For example, on the Public Broadcasting Satellite Interconnect System, the FOM analysis on the initial 133 sites was correct on the OK sites 96.15% of the time. Two-thirds of the INSPECT sites examined were ultimately determined to be OK. Of the MEASURE sites, 80.77% were ultimately determined OK, but only 26.67% of the sites categorized as MOVE sites were finally established to be OK sites. Thus, the summary of Figure 1 provides good validation for the overall approach.

FIGURE 1

PBS PROGRAM FOM VALIDATION

CATEGORY	PREDICTIONS	NUMBER COLLOCATED (OK)	PERCENTAGES
OK	26	25	96.15
INSPECT	51	34	66.67
MEASURE	26	21	80.77
MOVE	30	8	26.67
TOTALS	133	88	66.17

Similar results were obtained for the National Public Radio Satellite System, which as of this writing, has been fully coordinated, but has not yet been constructed. These results are given in Figure 2.

FIGURE 2

NPR PROGRAM FOM VALIDATION

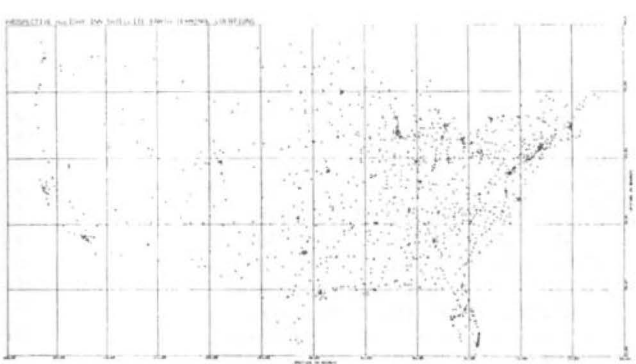
CATEGORY	PREDICTIONS	NUMBER COLLOCATED (OK)	PERCENTAGES
OK	57	55	96.49
INSPECT	60	50	83.33
MEASURE	30	17	56.67
MOVE	17	2	11.76
TOTALS	164	124	75.61

THE PROPOSED HOLIDAY INN SATELLITE SYSTEM

The most recent application of the FOM to a proposed large domestic satellite system was for that proposed by Holiday Inn for movie distribution to potentially 1533 inn locations in the U.S. Those locations are scattered over the entire U.S. as seen in Figure 3, and as such, the entire range of interference environments throughout the country will be encountered.

FIGURE 3

PROSPECTIVE HOLIDAY INN SATELLITE EARTH TERMINAL LOCATIONS



Since the proposed earth stations were to be used for video traffic, and were consequently wideband installations, SAFE counseled against attempting to make each earth station a transmit site in the 6 GHz band due to the heavy terrestrial environment depicted in Figure 4. Thus the FOM study was done to determine what proportion of the 1533 sites would work acceptably as receive-only sites in the 4 GHz band as depicted in Figure 5. The results of that study are given in the histogram of Figure 6.

FIGURE 4

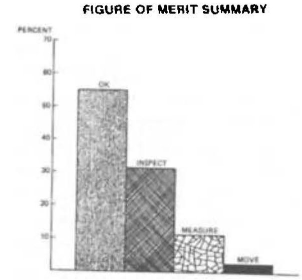
UNITED STATES ROUTE MAP — 6 GHZ

FIGURE 5

UNITED STATES ROUTE MAP — 4 GHZ

FIGURE 6

HOLIDAY INN FIGURE OF MERIT SUMMARY



CONCLUSIONS

The Figure-of-Merit approach to sizing domestic satellite systems has been validated by two large system applications and used in the planning stages of a third. As a tool for risk reduction, and "breakdown" of the planning of a large system such that logical program segments are addresed seperately, far more accurate cost and schedule information can be derived than would otherwise be possible. The OK sites can be established as a Phase I wherein the hardware will be essentially the same, and little site preparation costs related to shielding will be incurred. The INSPECT and MEASURE sites will require substantially more engineering to determine ultimate outcome,but the percentage figures of Figures I and 2 provide some general guidelines. And finally, the MOVE sites represent in general,new land acquisition or use of land other than that orginally planned. In many cases, these sites will require a terrestrial microwave link back to the original site.

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