The Radar Support System (RSS): A Tool for Siting Radars and Predicting Their Performance

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Abstract--The Radar Support System (RSS) is a software tool for assisting the radar siting engineer in determining the best location for a sensor, evaluating performance in a site-specific environment and analyzing operational problems. The RSS uses detailed sensor models, along with digital topographic, land cover and cultural databases, to provide accurate performance predictions. The RSS is currently being used by the FAA to assist in their sensor deployments and analyses.

I. RSS OVERVIEW

The Radar Support System (RSS), which is being developed for the Federal Aviation Administration (FAA), is a family of software tools for siting primary surveillance radars (PSRs), secondary surveillance radars (SSRs), data links and other equipment, and for predicting their in-the-field performance. Mr. William Collins of AND-400 is the FAA project leader. Fig. 1 illustrates the RSS software elements. The RSS also has the capability to predict the performance of a network of PSRs or of SSRs. A detailed tutorial on the RSS is available on the INTERNET at **http://www.tsc.com**.

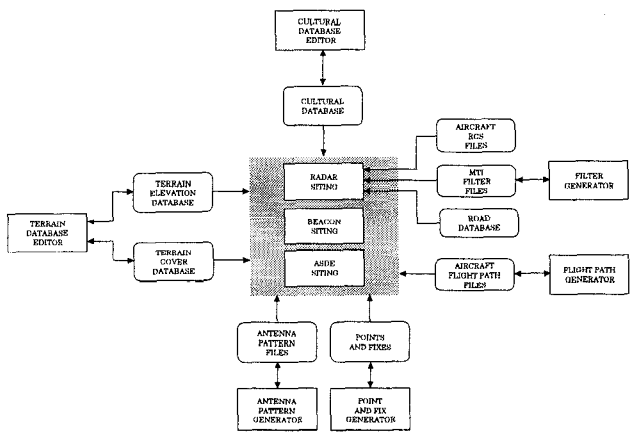

Fig. 1. RSS Software Elements

The RSS is a cost-effective tool that provides detailed siting data in a timely manner. The RSS analysis capabilities can assist the siting engineer in selecting the best location for the radar, in optimizing site-specific sensor parameters such as the sensor height, the beam tilt angle and the STC characteristics, and in determining factors such as the visibility of critical way points and where false alarms due to highway traffic or strong clutter returns might degrade the system performance. Measures-of-merit for site placement include the visibility of operator selected vectoring points, the runway visibility, the visibility of potential multipath regions, the visibility and orientation of highways, and the total volumetric coverage. This information facilitates both the site selection and the sensor installation. The RSS can be also used to assess sensor performance and to analyze operational problems for fielded equipment.

The RSS utilizes detailed sensor models, coupled with both digital terrain and land cover databases, as the basis for performing its analyses. Additionally, the AFRL developed several aspect angle-dependent target models that have been incorporated into the software. The use of these databases and target models makes the RSS unique when compared to other software siting tools that provide line-of-sight (LOS) analyses, but fail to evaluate environmental factors such as the ground and weather clutter return strength, target RCS, multipath and Doppler bandwidth effects, or the local road traffic. Such environmental effects, which can significantly impact the sensor's performance, must be considered during the sensor siting and the performance prediction processes.

The sensor parameters are input to the RSS through a series of pop-up menus, with default values stored for each sensor system that has been previously simulated. Among the PSRs that are presently modeled are the ASR-9, the ARSR-4 and the ASDE-3. The SSR tools in the RSS, which can simulate both specific and generic systems, predict both Mode A/C and Mode S performance.

Several site-specific performance measures are available for each sensor type. LOS coverage plots can be generated for all sensors types in both a range-azimuth and azimuth angle-obscuration (i.e. screening) angle format. Figs. 2 and 3

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present examples of these plots. Included on the plots are the points and fixes specified by the siting engineer. In addition, probability of detection (P_D) and probability of false alarm (P_{FA}) performance plots can also be generated in a number of user-selectable formats. An example range-azimuth format performance plot is illustrated in Fig. 4, while an example range-height format performance plot is illustrated in Fig. 5. The P_D and other performance values can also be determined for a user-specified aircraft flight path.

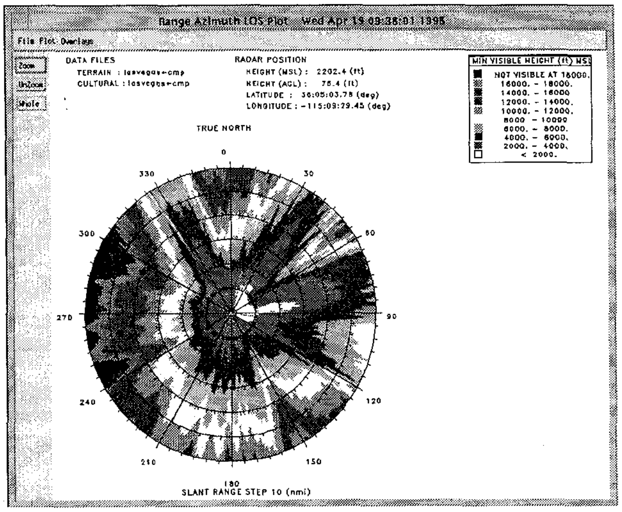

Fig. 2. LOS Visibility Plot

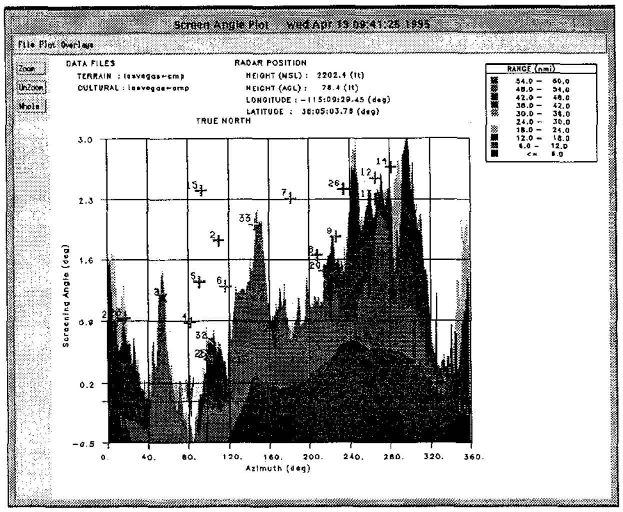

Fig. 3. Obscuration Angle Plot

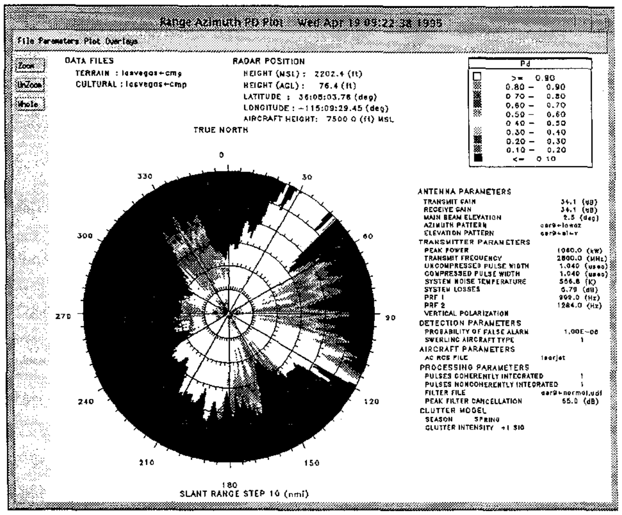

Fig. 4. Probability of Detection Plot in Range-Azimuth Format

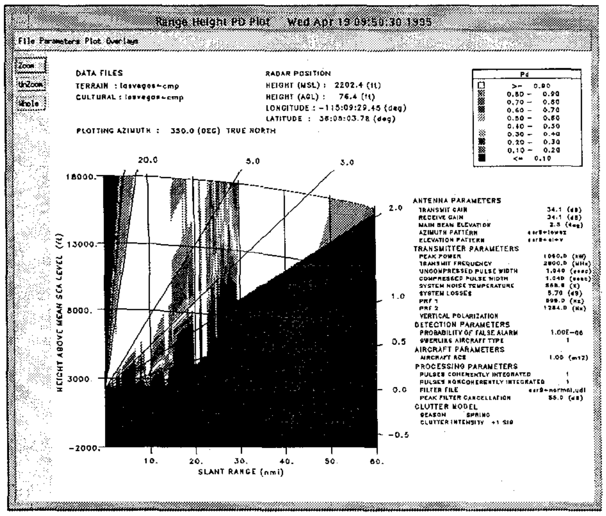

Fig. 5. Probability of Detection Plot in Range-Height Format

SSR performance is also available in a variety of output formats. For example, this data can be presented as the received signal-to-noise ratio (SNR) for the interrogator or the transponder, as the probability of correctly receiving a message on the uplink or the downlink path, or as the round-reliability of the entire system. Also available are plots of probable false beacon reply locations; such false replies are due to reflections from buildings and other structures.

Two validations of the clutter/LOS modeling have been performed. The first was performed by the MITRE Corporation, using data collected with an X-band radar at the Miramar Naval Air Station in California. The second validation was performed by Technology Service Corporation with the cooperation and support of Rome Laboratory, using the S-band radar located at their Rome, NY facility. Both comparisons showed that the LOS and clutter RCS processing of the RSS to be performing well within expected bounds. A third validation using an instrumented ASR-9 radar in Albuquerque, NM will be performed in 1997. Also during 1997 a validation of the ARSR-4 model will be performed.

The RSS has been used to support a number of sensor siting and analysis projects. For example, the RSS was used to assist in the siting of both PSRs and SSRs in Tunisia, and to provided performance data to the FAA's Central Region to aid in the justification of an ASR-9 radar site selection. Additionally, the RSS is currently being used by the FAA as a system evaluation tool, performing analyses of proposed sensor designs and hardware modifications in simulated site-specific environments. A variant of the RSS, known as the FIREFINDER Position Analysis System (FFPAS), has been developed for the US Army. The FFPAS is presently being used by the Army to site counter-battery radars in Bosnia and South Korea.

II. RSS OPERATION

The RSS, which operates under UNIX, has been developed using X-Windows and Motif. The software is coded in C and FORTRAN. At the present stage of its development the RSS models the performance of L–band through K_u-band PSRs. Fig. 6 illustrates the basic processing stages for an RSS radar performance analysis. Each stage of the processing will be discussed in the following subsections.

A. User Interface

The user interface to the RSS is through a menu-driven program from which the engineer can specify the parameters of the sensor system to be analyzed, detail the site-specific characteristics, and select from a set of output formats. The menu system allows the user the flexibility of performing analyses utilizing stored sensor parameter files, generating variations on the stored files, or creating additional parameter files describing new or developmental radar systems. Fig. 7 presents an RSS menu example. This particular menu is used to input the parameters for the sensor's transmit antenna.

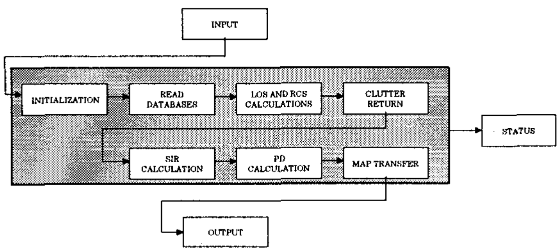

Fig. 6. RSS Processing Stages

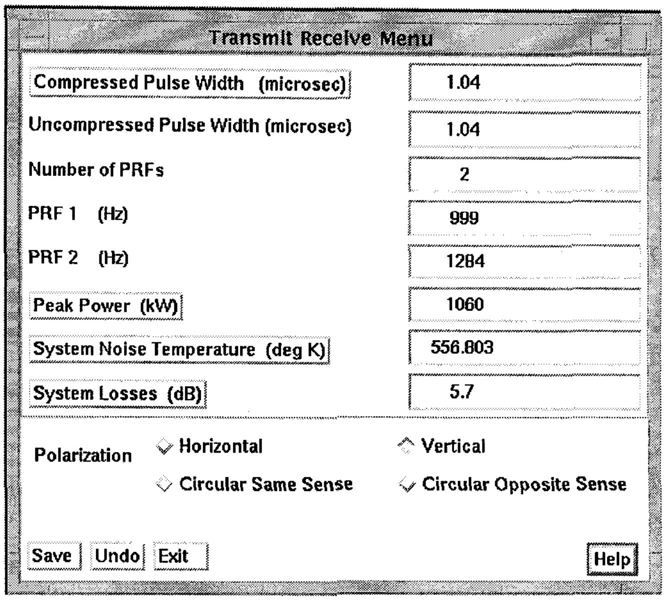

Fig. 7. RSS Menu Example

B. Databases

Three databases are used in the current version of the RSS to describe the local environment of the sensor. The first, illustrated in Fig. 8, is a Digital Elevation Model (DEM) that describes the topography of the locale. The DEM consists of a latitude/longitude grid of terrain elevations. The height resolution of this database is one meter, with steps in latitude and longitude of three seconds. This database is available from the United States Geological Survey (USGS) or from the Defense Mapping Agency (DMA).

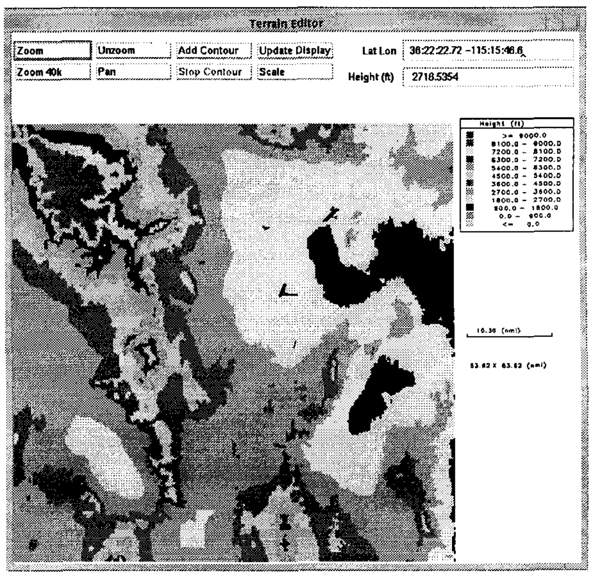

Fig. 8. Digital Terrain Height Database

The second required database, illustrated in Fig. 9, is the Land Use and Land Cover (LULC) model, which can also be purchased from the USGS. This database consists of a latitude/longitude grid of selected terrain cover types. The latitude and longitude resolution of the LULC database is also three seconds. For an ASR-9 analysis, the terrain height and the terrain cover databases typically encompass a 120 nmi square area centered at the airport. Significantly larger databases are required for an enroute system such as the ARSR-4.

The third database, which is optional but which is very important for urban sitings, is termed the cultural database. This database, illustrated in Fig. 10, is a collection of three-dimensional models of all of the significant buildings in the proximity of the airport. Each building is represented as a polygon, with each vertex of the polygon being defined by its latitude and longitude, the ground height (MSL) at the base and the height (MSL) of that point above the base. Also included is an estimate of the construction material of each structure. All buildings with a vertical projected area greater than 100 m^2 within 10 nmi of the airport are currently collected. The cultural database is typically collected from 1:40,000 aerial stereo photographs of the area using a specialized digital stereoplotter.

Another part of the RSS tool set is an interactive, graphics-based cultural database editor. This editor allows the analyst to permanently modify the cultural database to incorporate new construction in the vicinity of the airport. The editor also permits the analyst to make temporary changes in the cultural database, allowing, for example, the impact of proposed construction on existing radar sites to be determined.

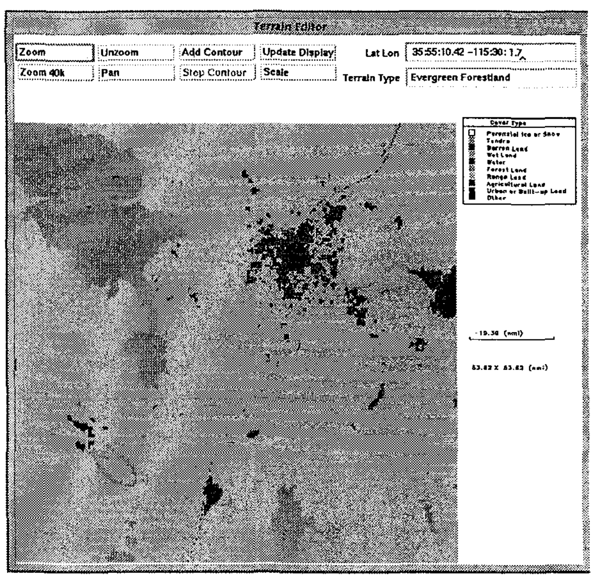

Fig. 9. Digital Terrain Cover Database

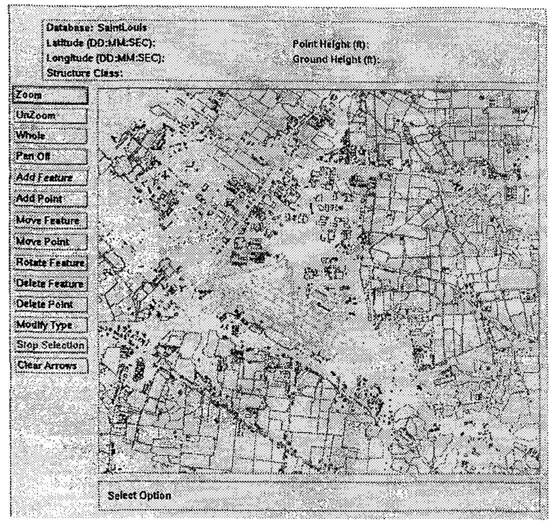

Fig. 10. Cultural Database

C. LOS Visibility Determination and Clutter Cancellation Processes

The LOS visibility determination and clutter calculation processes can be logically separated into the five stages shown in Fig. 6. (To minimize computational complexity and data storage requirements, some of these stages are intertwined.) In the first stage, the terrain databases are organized in a range/azimuth format, with an increasingly fine azimuth resolution as the range from the sensor location increases. This is done to ensure a minimum cross-range resolution, which is currently set to 100 m.

In the second stage, the RCS of all visible terrain cells is calculated using one of two parametric terrain backscatter models that have been chosen for use in the RSS. The first model, which is used at UHF, was formulated by the Air Force; the second model, which is used for L through X-bands, was developed by Ulaby and Dobson. Both models are valid for all incidence angles, ψ. The clutter reflectivity, σ_o, predicted by these models is:

UHF: $\sigma_o = C_1 + \gamma \sin(\psi) + C_2 \exp[-C_3/(\pi/2-\psi)]^{C4}$ m^2/m^2

and

L to X-band: $\sigma_o = P_1 + P_2 \exp(-P_3\psi) + P_4 \cos(P_5\psi + P_6$ dBm^2/m^2

The constants in these models are the terrain, season, polarization and frequency-dependent constants. The expressions are attractive because they allow independent calculation of the constants from separate sets of independent data points.

Model parameters have been determined empirically, based upon measurements of clutter RCS at UHF through X-band, for various terrain types at grazing angles ranging from near zero degrees to vertical incidence. For K_u-band radar modeling, the σ_o values have been estimated by extrapolation in frequency to support the ASDE-3 analyses.

The processing of the cultural database begins in Stage 3. Each building in the database is divided into a number of rough plate and dihedral surfaces. The RCS of each plate is calculated based on its visible area, the construction material, and the incident angle to the sensor, using a rough dielectric plate model. The RCS of each dihedral (which are composed to two plates connected at one vertical edge) is calculated based on the visible area of the composite plates, the construction material, the incidence angle for the sensor, and the dihedral angle between the plates. The LOS blockage of the individual plates and of the terrain behind each object is determined using geometrical optics.

The generation of the clutter maps is completed in Stage 4. (Separate maps are maintained for cultural and terrain cutter so that in later stages of RSS processing, the correct Doppler filter response can be determined). Each range-azimuth cell of the terrain and cultural RCS maps is multiplied by the corresponding transmit and receive antenna gains. The elevation gain is determined by the elevation angle from the sensor to the center of the terrain cell or cultural object. To determine the effect of azimuth sidelobes, the radar's azimuth antenna pattern is circularly convolved with each range ring of each clutter map. The resultant terrain and cultural RCS maps are re-sampled to the range resolution of the sensor being modeled, and are passed on to later stages of processing.

D. Signal-to-Interference Ratio Calculation

The Signal-to-Interference Ratio (SIR) routine calculates the SIR for a range/azimuth grid at a user-specified elevation, or a range/elevation grid for a user-specified azimuth. This is done using the radar range equation. Several moving target indicator (MTI) filtering options are available to the RSS user. The filter response to the actual terrain and cultural clutter, including antenna scanning effects, and to rain (if desired) is calculated. The filter options include delay-line cancellers, weighted Fourier transforms with any number of filters excised about zero frequency (i.e. DC), and user-defined digital filters, which can be used with either a single or dual PRF.

E. Probability of Detection Calculation

Calculating the Probability of Detection (P_D) from the SIR generated in the previous stage is done using the standard formulations. Based on the SIR, the desired Probability of False Alarm (P_{FA}), the Swerling target model, the CFAR loss for the local clutter type and the number of processor outputs to be non-coherently integrated, the estimated P_D is calculated for each cell. Because the calculation can be very complex, a lookup table of SIR versus P_D is generated. This is done in steps of 1% P_D. This procedure allows for rapid conversion of SIR to P_D over the many cells for which this calculation is desired.

F. Output Processing

The final step of a radar siting analysis is the generation of outputs. Two output devices are currently supported by the RSS: an X-window/PHIGS format monitor and a Hewlett Packard color ink jet printer

A significant variety of outputs are currently available in the RSS for both PSRs and SSRs. These outputs include:

Terrain Contour Maps
Range/Azimuth LOS Plots
Range/Azimuth Clutter Plots
Range/Azimuth Performance Plots
Range/Height Performance Plots
Plan view Performance Plots of Flight Corridors
Range/Azimuth False Alarm Plots
Obscuration (i.e. Screening) Angle versus Range Plots
Beacon False Target Detection Plots

III. ASR-9 OPTIMIZATION

Software incorporated into the RSS allows the user to optimize several of the Variable Site Parameters (VSPs) available in the ASR-9. For this, the user specifies a range of antenna tilt angles to be evaluated; then, for each tilt angle, both the STC and the High Beam/Low Beam window parameters are optimized by the RSS. The STC optimization attempts to maintain an 80% P_D over the desired detection volume, while the High Beam/Low Beam settings are selected to minimize the number of receiver saturations. Weighted performance measures, including the number of remaining receiver saturations, the point/fix visibility and the detection performance are then used to select an optimal tilt angle. Table I presents an example of a point/fix visibility analysis, while Table II shows an example of an optimized VSP determination.

IV. FUTURE RSS ENHANCEMENTS

Many enhancements are being considered by the FAA and AFRL for incorporation into the RSS. These include the modeling of additional sensors such as the Terminal Doppler Weather Radar (TDWR), Parallel Runway Monitors, the ASR-8, ASR-11 and AN/TPS-75 radars, and of enroute communications equipment. The primary planned improvement to the siting software is the capability to auto-

TABLE Ii

POINT/FIX VISIBILITY ANALYSIS

RADAR LOCATION DATA :

LATITUDE (DEG MIN SEC)	LONGITUDE (DEG MIN SEC)	ELEVATION (FT MSL)	ANTENNA HT (FT)
36 05 04	-115 09 26	2195.9	76.4

FIX DATA :

NO.	NAME		LATITUDE (DEG MIN SEC)	LONGITUDE (DEG MIN SEC)	RNG (NMI)	AZ (DEG-TRUE)	SCREEN ANGLE (DEG)	REQ ALT (FT MSL)	ADJ ALT (FT MSL)	SCREEN ALT (FT MSL)	VISIBLE	PD
1	LAS VOR		36 04 47	-115 09 35	0.31	202.89	-1.517	2440.0	****IN DEAD ZONE****			0.000
2	BLD VOR	*	35 59 45	-114 51 49	15.26	110.29	0.675	5300.0	5171.1	3442.6	YES	0.992
3	OVETO	*	36 27 38	-114 30 29	38.76	54.24	1.406	8000.0	7672.3	8971.3	NO	× 0.000
4	MEADS		36 09 49	-114 29 30	32.72	81.46	-0.207	6000.0	5723.0	2186.1	YES	× 0.970
5	CROWE		36 04 26	-114 19 56	40.16	90.65	0.368	9000.0	8660.8	4930.5	YES	× 0.943
6	WINDS		35 51 23	-114 35 56	30.45	116.49	0.455	7000.0	6742.5	4280.4	YES	× 0.982
7	CRESO	*	35 46 27	-115 09 55	18.62	181.18	0.838	7000.0	6843.0	4079.7	YES	0.993
8	WHIGG		35 30 29	-115 31 25	38.92	207.48	1.139	10000.0	9671.6	7901.6	YES	× 0.955
9	CLARR		35 40 33	-115 40 47	35.36	226.28	1.587	10000.0	9701.9	8975.9	YES	× 0.972
10	OASIS		35 54 15	-115 23 12	15.56	226.03	1.296	7400.0	7269.1	4494.5	YES	0.989
11	HARLS		36 04 01	-115 22 44	10.85	264.54	1.361	6000.0	5908.7	3838.9	YES	0.992
12	LUCKY		36 02 20	-115 50 42	33.61	265.53	2.101	12000.0	11717.6	10432.6	YES	× 0.976
13	HIDEN		36 01 42	-116 00 37	41.68	265.63	2.116	13500.0	13149.9	12697.8	YES	× 0.946
14	FUZZY	*	36 12 02	-115 54 01	36.83	281.13	2.453	13500.0	13191.1	12672.7	YES	× 0.965
15	HAWKO		36 04 35	-114 57 15	9.90	92.75	-0.556	4800.0	4716.5	1677.3	YES	0.992
16	LAS 075/2.7		36 04 35	-115 06 51	2.15	103.03	-0.862	2200.0	2181.8	2002.2	YES	0.881
17	LAS ARPT		36 04 58	-115 09 13	0.21	118.12	-3.419	2415.0	****IN DEAD ZONE****			0.000
18	KLSV ARPT		36 14 41	-115 01 27	11.58	33.93	-0.348	2154.0	2055.8	1857.8	YES	0.798
19	VGT ARPT		36 12 45	-115 11 46	7.90	346.22	-0.056	2507.0	2440.1	2190.7	YES	0.922

* INDICATES PRIMARY FIX

× INDICATES FREE SPACE PD (BEYOND MAX PLOT RANGE)

TABLE II

OPTIMIZED VSP DETERMINATION

```
SITE LATITUDE  =  36 DEGREES  5 MINUTES    3.78887 SECONDS
SITE LONGITUDE = -115 DEGREES  9 MINUTES   29.4578 SECONDS

 1.2 optimum tilt angle in degrees

vsp   1501      82.0 - low beam reference attenuation
vsp   1502       120 - low beam STC slope (0.1 db/octave)
vsp   1503       121 - low beam STC slope (0.1 db/octave)
vsp   1504       120 - low beam STC slope (0.1 db/octave)
vsp   1505       165 - low beam STC slope (0.1 db/octave)
vsp   1506        42 - low beam STC slope (0.1 db/octave)
vsp   1507         1 - low beam STC slope (0.1 db/octave)
vsp   1508        22 - low beam STC slope (0.1 db/octave)
vsp   1509         0 - low beam STC slope (0.1 db/octave)
vsp   1601      76.0 - high beam reference attenuation
vsp   1602       120 - high beam STC slope (0.1 db/octave)
vsp   1603       135 - high beam STC slope (0.1 db/octave)
vsp   1604       124 - high beam STC slope (0.1 db/octave)
vsp   1605       149 - high beam STC slope (0.1 db/octave)
vsp   1606         6 - high beam STC slope (0.1 db/octave)
vsp   1607         0 - high beam STC slope (0.1 db/octave)
vsp   1608         0 - high beam STC slope (0.1 db/octave)
vsp   1609         0 - high beam STC slope (0.1 db/octave)
 8 # of inner regions
vsp   1101        64 - start az adjct window (cpis)
vsp   1102        96 - start az adjct window (cpis)
vsp   1103       128 - start az adjct window (cpis)
vsp   1104       160 - start az adjct window (cpis)
vsp   1105       191 - start az adjct window (cpis)
vsp   1106       195 - start az adjct window (cpis)
vsp   1107       209 - start az adjct window (cpis)
vsp   1108       217 - start az adjct window (cpis)
vsp   1109        15 - range for adjct window (nmi)
vsp   1110        15 - range for adjct window (nmi)
vsp   1111        15 - range for adjct window (nmi)
vsp   1112        15 - range for adjct window (nmi)
vsp   1113        17 - range for adjct window (nmi)
vsp   1114        15 - range for adjct window (nmi)
vsp   1115        17 - range for adjct window (nmi)
vsp   1116        15 - range for adjct window (nmi)
 2 # of is regions
isolated window # 1
vsp   1201       215 - start az isolated beam (cpis)
vsp   1202         4 - az extent isolated beam (cpis)
vsp   1203        24 - start range (nmi)
vsp   1204        25 - stop range (nmi)
vsp   1205           - high beam window
isolated window # 2
vsp   1206       203 - start az isolated beam (cpis)
vsp   1207         3 - az extent isolated beam (cpis)
vsp   1208        18 - start range (nmi)
vsp   1209        20 - stop range (nmi)
vsp   1210           - high beam window
```

matically select the best sites for sensor placements, based on operator-selected geographical constraints. Measures-of-merit for site placement will include the visibility of operator selected vectoring points, the runway visibility, the visibility of potential multipath regions, the visibility and orientation of highways, and the total volumetric coverage.

V. SUMMARY

In its current stage of development, the RSS provides a powerful tool for predicting the site-specific performance of PSR and SSR systems. By automating the site selection process, the RSS will help to significantly reduce the time required and the cost of sensor siting, while affording the siting engineer the opportunity to evaluate more than the handful of sites currently investigated when a new sensor location is to be chosen. Future RSS enhancements will provide this same benefit for other equipment, and will help to bring about an even higher level of siting automation.