N94-21344

SATELLITE COMMUNICATION HARDWARE EMULATION SYSTEM (SCHES)

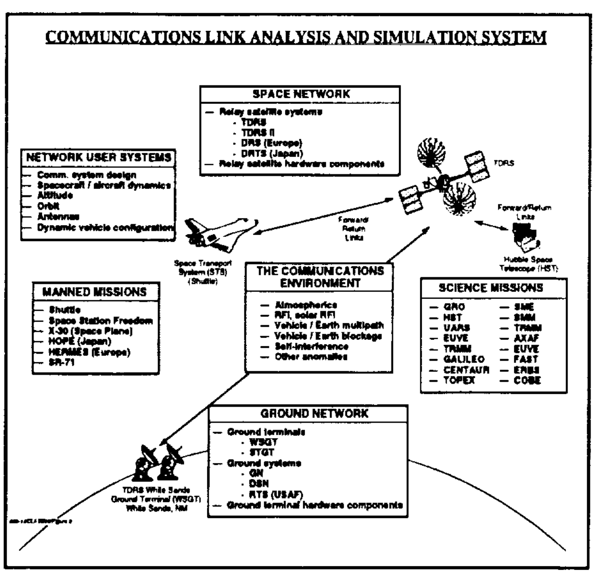
By Ted Kaplan

Stanford Telecom
7501 Forbes Blvd
Seabrook, MD 20706
(301) 464-8900

ABSTRACT — Satellite Communication Hardware Emulator System (SCHES) is a powerful simulator that emulates the hardware used in TDRSS links. SCHES is a true bit-by-bit simulator that models communications hardware accurately enough to be used as a verification mechanism for actual hardware tests on user spacecraft. As a credit to its modular design, SCHES is easily configurable to model any user satellite communication link, though some development may be required to tailor existing software to user specific hardware.

I. INTRODUCTION

The Communications Link Analysis and Simulation System (CLASS) has been developed by Goddard's Networks Division to provide a tool for evaluating the performance of space communication links through the network communications and tracking support elements, especially TDRSS. Subsequent enhancements and extensions of the system have expanded the CLASS system capability to provide a general-purpose communications system analysis and design tool for use by both the network and the network user. CLASS models all elements of the network system, user system, and communications channel environment. It is capable of providing a rapid, reliable, and accurate performance analysis of virtually all communications system performance measures.



CLASS, developed to evaluate the performance of space communication links through network communications and tracking support elements.

II. SCHES OVERVIEW

Most recently, the CLASS team has developed the Satellite Communication Hardware Emulator System (SCHES), a powerful simulator that emulates the hardware used in TDRSS links. SCHES is a true, bit-by-bit simulator that models communications hardware accurately enough to be used as a verification mechanism for actual hardware tests on user spacecraft. As a credit to its modular design, SCHES easily is configurable to model any user satellite communications link, though some development may be required to tailor existing software to user-specific hardware.

Hardware modules in the communication link are simulated effectively in SCHES using separate software modules. Each of these modules uses compatible input and output files which consist of data streams for the bit-by-bit simulation. The input file for any one hardware simulation module acts as the driver for that module. That module, in turn, produces an output file which drives the next module, while additionally allowing for the calculation of statistics at crucial points between modules. These analytical statistics provide otherwise unobtainable information on the performance of each individually modeled hardware subsystem. Finally, the individual simulation outputs are combined and analyzed to produce a complete and accurate representation of the proposed user satellite link.

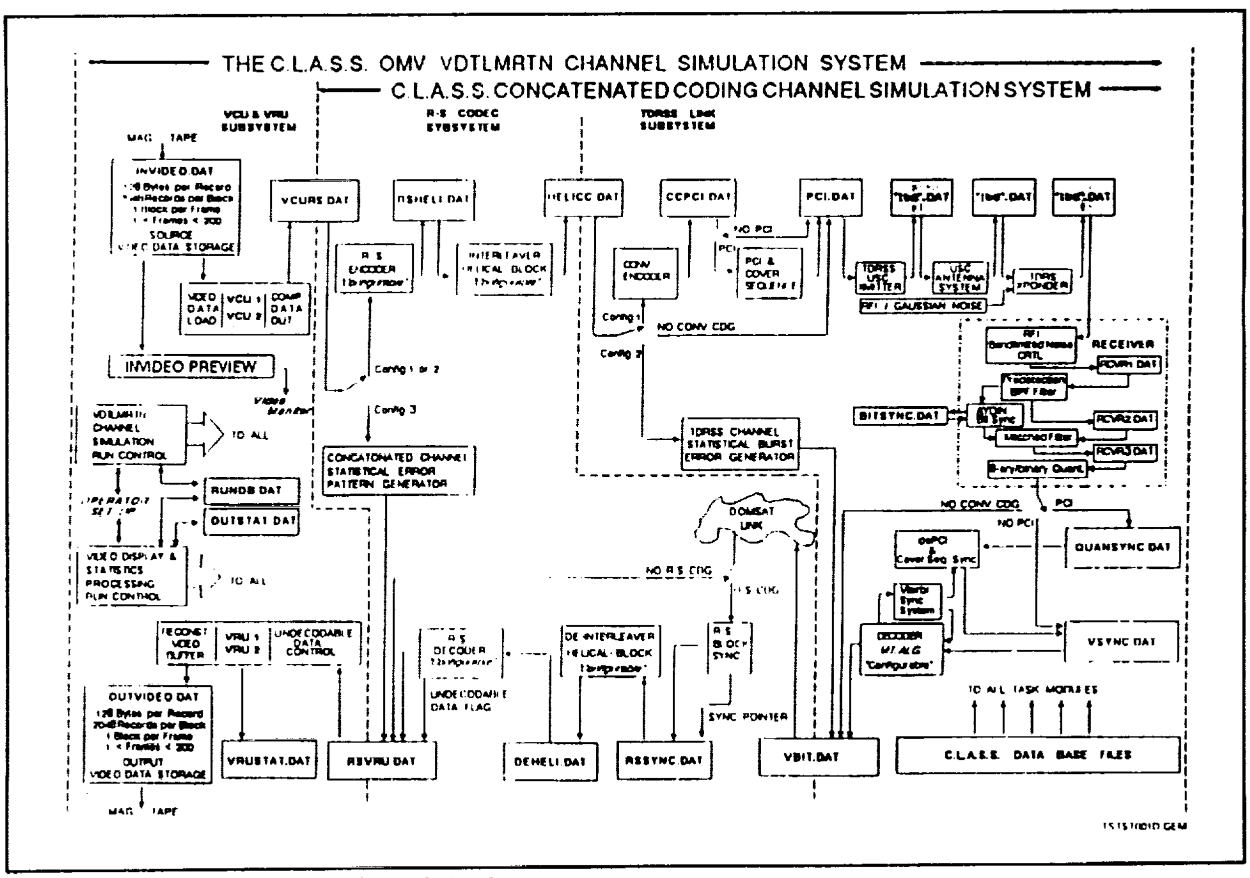
This simulation approach requires the processing of statistically significant sample spaces which usually means much larger data bases than are required by an analytical approach. Nonetheless, there are powerful advantages to this true simulation approach: it serves not only as an analysis tool but also as a design tool, for the flexibility to alter individual channel elements enables to observe the effects these changes have on the overall channel performance. In particular, it affords us the ability to characterize the transient features of TDRSS.

When large amounts of data have been collected on the behavior of a particular hardware module, a true hardware simulation for that hardware subsystem may no longer be necessary. Instead, the simulation can be replaced with a functional model that uses appropriate statistics to corrupt the digital data stream. This functional model can provide the same accuracy as the direct emulation model, when predicting steady-state channel performance, but with the potential for enormously increased simulation run speeds.

The computational support for SCHES is provided by software hosted on an HP9000 computer, running under a UNIX operating system environment. The system includes a user-friendly interface for run control, provided on a Macintosh II. The capability to visually monitor test run activities is supported through the use of a video monitor.

III. IMPLEMENTATION FOR OMV

SCHES was tested during the course of a task to develop a complete model simulation of the Orbital Maneuvering Vehicle (OMV) video te-



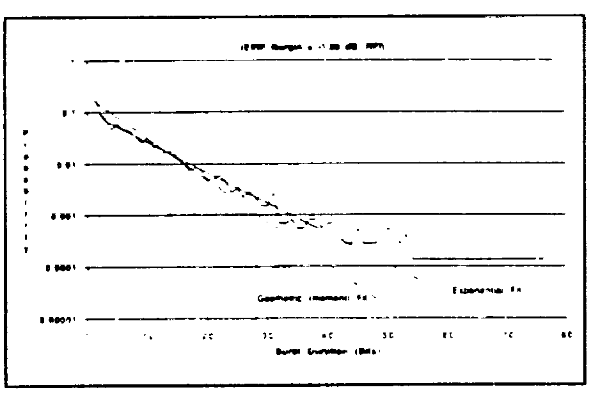
A block diagram of the CLASS channel simulation system.

lemetry return link. OMV was to be a remotely piloted spacecraft, designed to be part of the space transfer system.

The OMV video signal needed to be extremely robust to allow the pilot on the ground to view a target. Video compression and forward error correction, as described below, ensured the quality of the picture at the ground terminal. The camera's video signal was first digitized and compressed by 2-D differential pulse code modulation and Huffman coding. Error resistance was added through the use of Reed-Solomon encoding and Helical interleaving. A rate - 1/2 convolutional code was added with periodic convolutional interleaving so that the data could be relayed via TDRSS. Then, from White Sands Ground Terminal, the data was sent to Johnson Space Center via DOMSAT.

The pilot's commands to the OMV vehicle were transmitted by the forward link. Errors in the data transmission, however, were expected to result primarily from thermal noise and radio frequency interference (RFI) corruption of the TDRSS S-band return link between the OMV flight vehicle and the TDRSS spacecraft.

The essential concepts of the SCHES model of the OMV channel simulation are illustrated in the second figure.



Exponential and geometric fits to burst duration statistics

The model is separated into three subsystems: the video compression unit and video reconstruction unit, which are modules unique to OMV; the Reed-Solomon coder-encoder subsystem; and the TDRSS link subsystem, which is part of standard CLASS. Each subsystem is further divided into modules. Each module simulates a hardware function and produces a data file which, in turn, drives the next module.

The DOMSAT link was not discretely modeled in the SCHES simulation because the BER through this link was reduced, through forward error correcting, to very low value. The other blocks in the system were exact, bit-by-bit hardware emulations of the actual system and together were used to characterize both transient (synchronization) behavior as well as static behavior of the channel.

IV. RESULTS

More than 20 simulations of the OMV return video link were completed, each requiring 25 hours of run-time. Runs were made with 50 frames apiece of data (approximately 5 million bits), and had varying effective isotropic radiated power (EIRP) margins and RFI environment conditions. The hardware simulation and the many test points provided the user with equivalent information to that acquired from actual hardware tests. Statistical processing was done by manipulating the data files after the simulation was over and by producing plots, histograms, and tables.

Statistics from different runs were plotted versus EIRP margin for each RFI condition. This data provided an easily understood statistical display of the actual performance characteristics of the video channel under varying environmental conditions.

Examples of some of the statistics produced are shown in the table and the third figure. These statistics are for an OMV communications link through TDRS-East, in a high RFI environment and with an EIRP margin of -1.5 dB. The fourth figure shows both the original picture frame (upper left), the reconstructed video display (lower right), as well as relevant channel statistics, as they appeared at run-time on the video monitor.

Summary of OMV when Operating with a 1.5-dB EIRP Margin in a Worst-Case TDRS-East Environment

Channel Characteristics	Units	Value
Analysis ID	-	A908041411
RFI	-	SSA.TDRS.EAST
EIRP Margin	dB	-1.5
Data rate	Kbps	972
Number of lines per subframe	-	20
Initial stepsize	-	16
Number of frames	frames	50
Number of codewords transmitted	codewords	2390
Number of (convolutionally coded) symbol.s	symbols	9,751,200

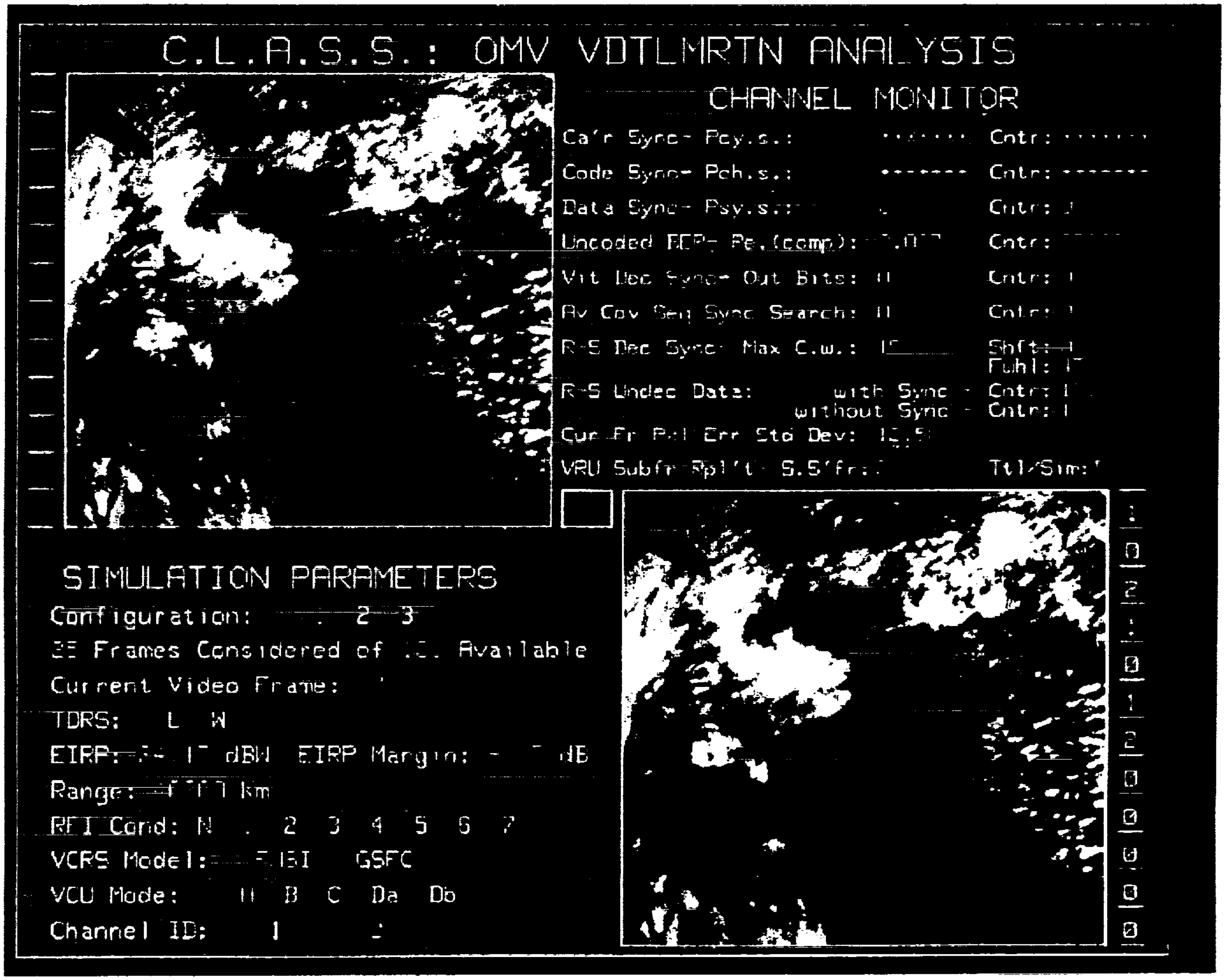
Statistics Before DE-PEI	Units	Value
Mean Clock Jitter	% of symbol	-0.57
Standard Deviation of the Clock Jitter	% of symbol	2.18
Symbol Slip Rate	-	0
Random Error Rate	-	1.17E-2
Number of Bursts	bursts	186,577
Burst Window	symbols	12
Mean Burst Error Duration	symbols	13.68
Standard Deviation of Burst Error Duration	symbols	11.10
Mean Errors Per Burst	symbols	3.96
Standard Deviation of Errors Per Burst	symbols	2.43
Mean Space Between Errors in a Burst	correct symbols	3.54
Standard Deviation of Space Between Errors in a Burst	correct symbols	3.12
Error Rate Due to Burst $\frac{\text{(\# of Bursts) (Mean \# of Errors Per Burst)}}{\text{Number or Symbols Transmitted}}$	-	7.58E
Total Error Rate = (Error Rate Due to Bursts) + (Random Error Rate)	-	8.7E-2
Transition Probabilities		
Pr(0/1)	-	.61274
Pr(1/1)	-	.12864
Pr(2/1)	-	.09934
Pr(3/1)	-	.06842
Pr(4/1)	-	.04940
Pr(5/1)	-	.02341
Pr(6/1)	-	.01091
Pr(7/1)	-	.00714
Pr(7/0)	-	.61286
Pr(6/0)	-	.12810
Pr(5/0)	-	.09973
Pr(4/0)	-	.7571
Pr)3/0)	-	.04215
Pr(2/0)	-	.02348
Pr(1/0)	-	.01075
Pr(0/0)	-	-00722
Predicted Viterbi Decoder Error Rate	-	2.64E-3
Analysis ID	-	A908041411

Summary of OMV when Operating with a 1.5-dB EIRP Margin in a Worst-Case TDRS-East Environment

Statistics After DE-PEI	Units	Value
Random Error Rate		1.17E-2
Number of Bursts	bursts	198,021
Burst Window	symbols	12
Mean Burst Error Duration	symbols	14.93
Standard Deviation of Burst Error Duration	symbols	12.20
Mean Errors Per Burst	symbols	3.73 Standard
Deviation of Errors Per lburst	symbols	2.17
Mean Space Between Errors in a Burst	correct symbols	4.10
Standard Deviation of Space Between Errors in a Burst	correct symbols	3.08
Error Rate Due to Bursts	-	7.57E-2

Statistics After the Biterbi Decoded	Units	Value
Total Error Rate.	-	5.219E-3
In-Sync Error Rate	-	5.219E-3
Number of Bursts	bursts	4730
Burst Window	bits	6
Mean Burst Error Duration	bits	7.96
STandard Deviation of Burst Error Duration	bits	6.84
Mean Errors Per Burst	bits	4.77
Standard Deviation of Errors Per Burst	bits	3.75
Longest Burst	bits	57

Statistics After the Reed Solomon Decoding	Units	Value
Undecodable Codewords in-Sync	Codewords	162
Undecodable Codewords Out-of-Sync	Codewords	28
Decodable Codewords In-Sync	Codewords	2209
Decodable Codewords Out-of-Sync	Codwords	0.0
In-Sync Codeword Error Rate	-	.068
First In-Sync Codeword a) The first 8 codewords are dummy data used in initialize the helical interleaver. b) A codeword is declared in-sync when its sync counter value stays at 15 for two codewords.	-	20
First Decodable Codeword After Declaring In-Sync	-	29
Number of Freewheeling Events	-	47 Lowest
Freewheeling Value	-	14
Max Sync Counter Value	-	2
Number of Subframe Replacements During Initial Sync	Subframes	24
Number of Subframe Replacements After Initial Sync	Subframes	148
Total Number of Subframes	Subframes	600



The video monitor display for the OMV analysis.

INTERFERENCE MONITOR

By Jeffrey Freedman and Catherine Ruseau

Stanford Telecom
7501 Forbes Blvd.
Seabrook, MD 20706
(301) 464-8900

ABSTRACT – Stanford Telecom developed the Interference Monitor (IM) for NASA Goddard Space Flight Center's (GSFC) Communications Link Analysis and Simulation System (CLASS). IM is a software program used to predict long term (i.e. 30+ years) statistics for mutual interference intervals of TDRS user spacecraft.

I. INTRODUCTION

TDRS user spacecraft periodically lose communication signals due to mutual interference. Mutual interference is defined as the interference between two spacecraft attempting to communicate with the same TDRS satellite at the same time. If the TDRS antenna discrimination is sufficient, two spacecraft can communicate at the same time with the same TDRS without mutual interference. However, when the user spacecraft appear close to each other (from point of view of TDRS), mutual interference may occur and communications can be lost.

The Interference Monitor (IM) was developed to predict long term statistics for intervals of mutual interference. IM simultaneously simulates the orbits of multiple user spacecraft while gathering interference statistics over long periods of time. IM can simultaneously simulate 100 user spacecraft orbits at 1 second intervals over a 30-year period. By examining many years of calculated orbits, IM can present an accurate statistical depiction of when, where and how much mutual interference will impair a user spacecraft's ability to communicate. The output plots and charts produced by IM provide NASA with accurate data for network and mission planning, interoperability studies and TDRS load analyses. What follows is an in-depth description of the analysis and the capabilities of IM.

II. ANALYSIS

IM uses an analytic pre-processing module and a simulation module to determine mutual interference statistics. The pre-processing module performs all the communications analysis in advance, and determines the conditions under which mutual interference can occur. The simulation module records statistics for user spacecraft as they meet these conditions.

The angle between two user spacecraft as seen from TDRS will determine if there is potential mutual interference between the two user spacecraft. This angle is called the inter-user angle and is shown in Figure 1. Separate antennas on TDRS communicate with each user spacecraft. The boresight of the TDRS antennas are pointed at the appropriate user spacecraft. As long as the inter-user angle is large, the interfering signals are transmitting to back lobes of the other antennas and mutual interference is negligible. However, when the inter-user angle is small, the interfering signals are transmitting to the main-lobe of the other antenna and communications can be lost.

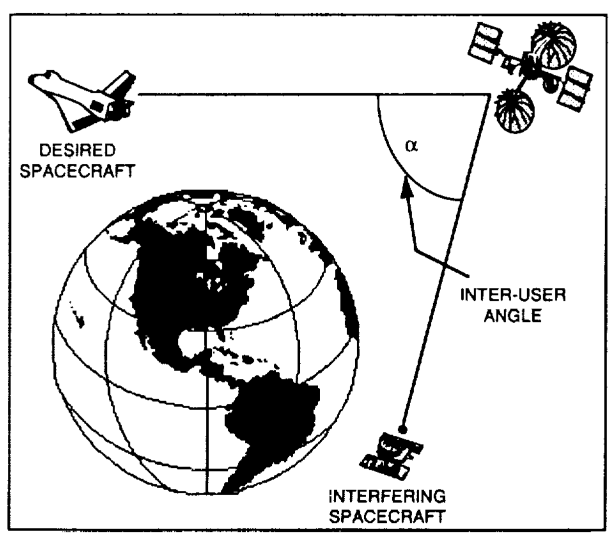


Figure 1. INTER-USER ANGLE - The angle, α, between the desired ad interfering user spacecraft

Figure 2 is a block diagram describing the operation of the program. IM first determines the minimum inter-user angles for which reliable communications between each pair of user-spacecraft can be maintained. This calculation is performed by the The CLASS Automated Conflict Resolution Sytem (ACRS) [1] which takes into account all communication parameters and the antenna pattern in determining the minimum inter-user angle.

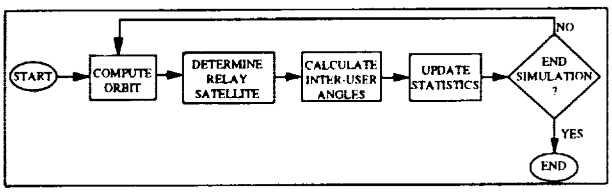


Figure 2. IM Block Diagram

The minimum inter-user angles are then fed into the IM simulation engine. The IM engine performs a point-by-point simulation of each spacecraft's orbit. At each point, the spacecraft's location is determined. IM then assumes that each spacecraft communicates with the nearest visible relay satellite. The inter-user angle between each pair of spacecraft are calculated, and if the inter-user angle is less than the minimum angle computed by ACRS, statistics are recorded. Time is then incremented and the process is repeated.

The orbit generator used by IM was developed specifically for this project and uses a simple geometric model. From the input orbital parameters, the orbit period, the precession rate and the initial orbit are determined. These computed orbital elements are used to calculate the location of the user spacecraft in the orbit plane. Next, the orbit plane is rotated by the inclination angle and spun about the earth's axis at the precession rate, as shown in Figure 3.

IM's orbit generator is designed for speed rather than accuracy so long term statistical data can be calculated quickly. Since it is impossible to predict exact orbits for an extended period of time anyway, the statistical output is sufficiently accurate.

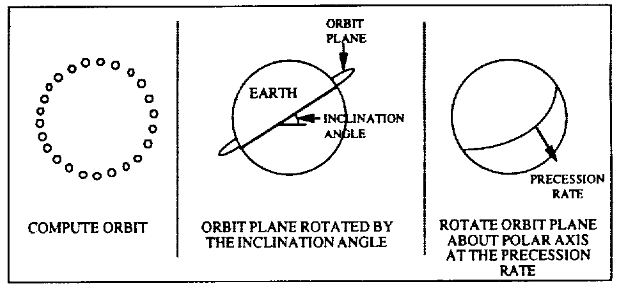


Figure 3. IM Orbit Generator

III. IM CAPABILITIES

IM has many features which make it a versatile tool for evaluating long term mutual interference. In a single simulation, IM can incorporate as many as 100 different user spacecraft, implement several different communication plans and derive mutual interference predictions from years of communication data which has been sampled at increments of time as small as a second. Each communication plan considers a different number of frequency channels and/or different frequency assignments for each user spacecraft. IM can demonstrate when, how much and with whom long-term mutual interference occurs for various communication plans. In addition to the numeric results, IM can reveal where mutual interference occurs utilizing an interactive graphics display.

The ability to incorporate different communication plans in a single simulation make IM a useful tool for frequency planning. The number of communication channels can be varied to create different communication plans within a single simulation. By varying the number of channels , optimal frequency allocations can be identified. Special users can be added or eliminated and their PN coding ability can be turned on or off to determine if PN coding will provide mutual interference isolation.

Mutual interference statistics provided by IM include: the percentage of days with a certain number of minutes of mutual interference, the maximum hours of daily mutual interference and the maximum hours of weekly mutual interference. IM produces mutual interference statistics for each active user spacecraft. Each IM simulation can consider an individual user spacecraft against every other individual spacecraft (see

Figure 4) or against a particular combination of any or all of the other user spacecraft (see Figure 5).

Figures 4 and 5 are statistics from a 25-year run. IM simulated a 25-year period in 1 minute steps and simultaneously gathered statistics for 36 spacecraft. The entire simulation took approximately 3 hours on an HP 9000 model 730 computer. Figure 4 shows the mutual interference between two EOS satellites. It shows that less than 1 percent of the days had mutual interference that was greater than 40 minutes in duration. Figure 5 shows the mutual interference between an EOS satellite and 36 other satellites. Notice that over 1 percent of the days had mutual interference periods greater than 130 minutes.

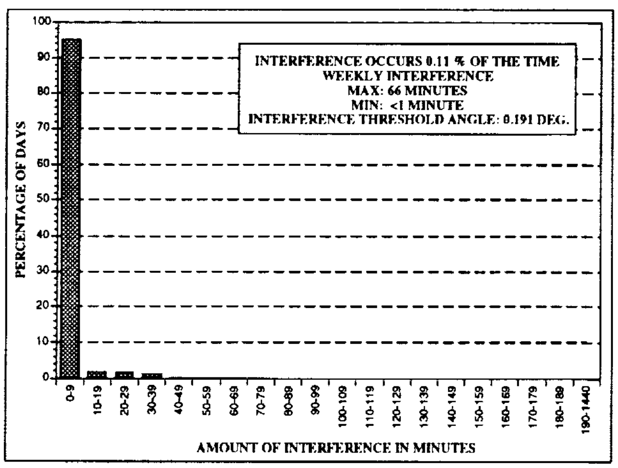


Figure 4. EOS1 vs. EOS2

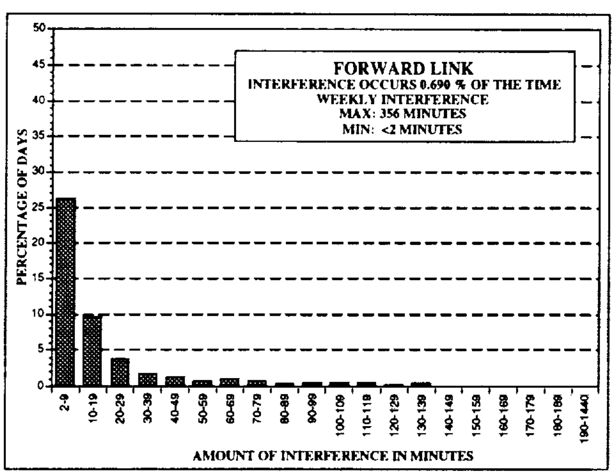


Figure 5. EOS1 vs. All Other Users

IM can also characterize when mutual interference occurs by producing a time-line chart (see Figure 6). The time-line interference chart displays when coverage loss due to mutual interference occurred over the time-line of a given day. Figure 6 depicts the time-line of a worst mutual interference day. A worst day for a desired user is defined as the day with the smallest number of total contact minutes. Coverage loss due to mutual interference includes any period of mutual interference and any contact period less than 10 minutes. The horizontal bars indicate when mutual interference and Zone of Exclusion (ZOE) outages occurred. The total number of contact minutes and the longest period of time with no contact are also displayed on the chart.

To visualize where mutual interference occurs, the IM interactive graphics mode is available. The interactive graphics mode displays up to three active user spacecraft and the location of mutual interference events on world maps. Maps of the world from the view point of each TDRS satellites are available as well as a flat map of the entire world (see Fig. 7.) Flags are displayed on the map in the location where mutual interference occurred. As the simulation progresses, flags collect and areas that experience the most mutual interference can be identified. At any given time, the IM graphics simulation can be interrupted and communication and orbital parameters of any or all of the user spacecraft altered to determine feasible mutual interference mitigation techniques.

The example shown in Figure 7 is a gray scale print of a color screen. The flags that represent mutual interference make a cross-hatch pattern in-between the continuous sinusoid dotted lines of the orbital paths of the spacecraft (note that the orbital paths of the spacecraft and the flags representing mutual interference are much more apparent when displayed in full color.) In Figure 7, the areas identified with the most mutual interference are immediately before and after the ZOE over the Indian Ocean. Mutual interference is more likely to occur in these areas because the inter-user angles are decreased when user spacecraft are near TDRS horizons.

IV. CONCLUSION

Interference Monitor predicts long term mutual interference statistics between two or more

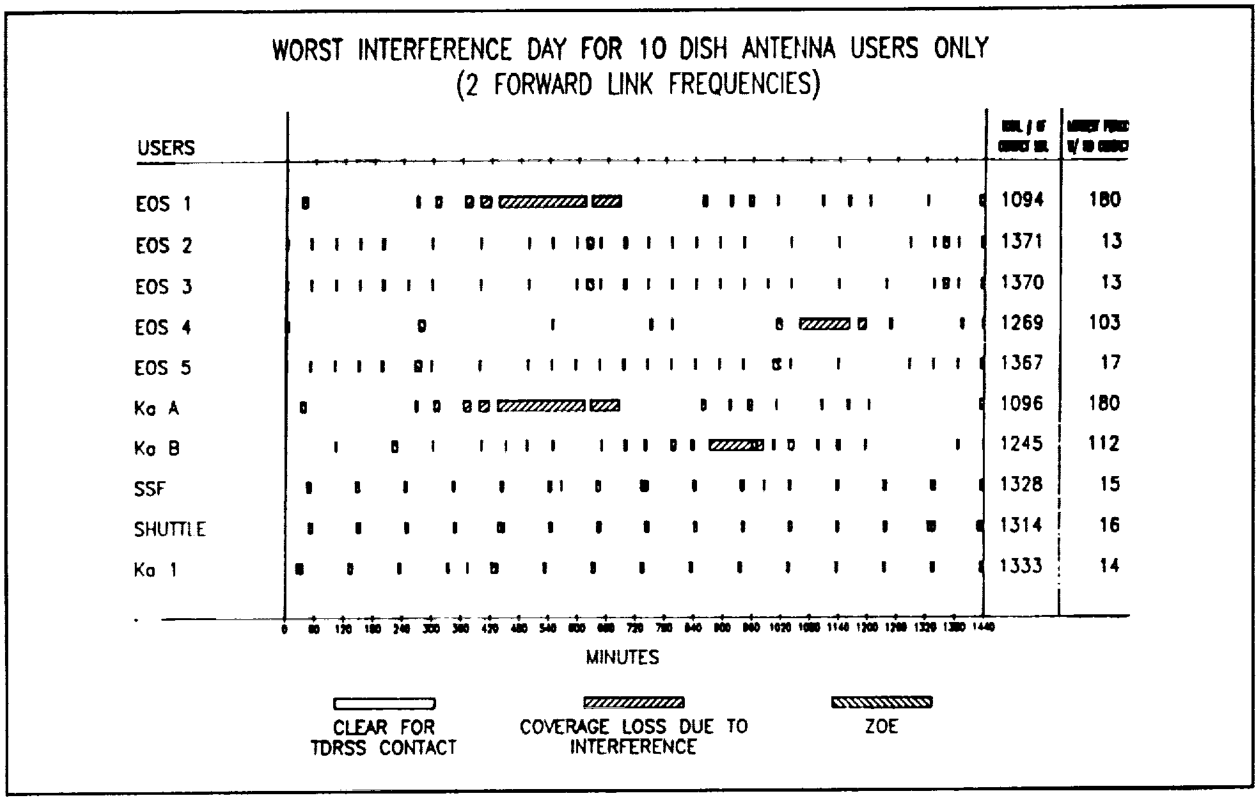


Figure 6. Time-Line for Worst Interference Day

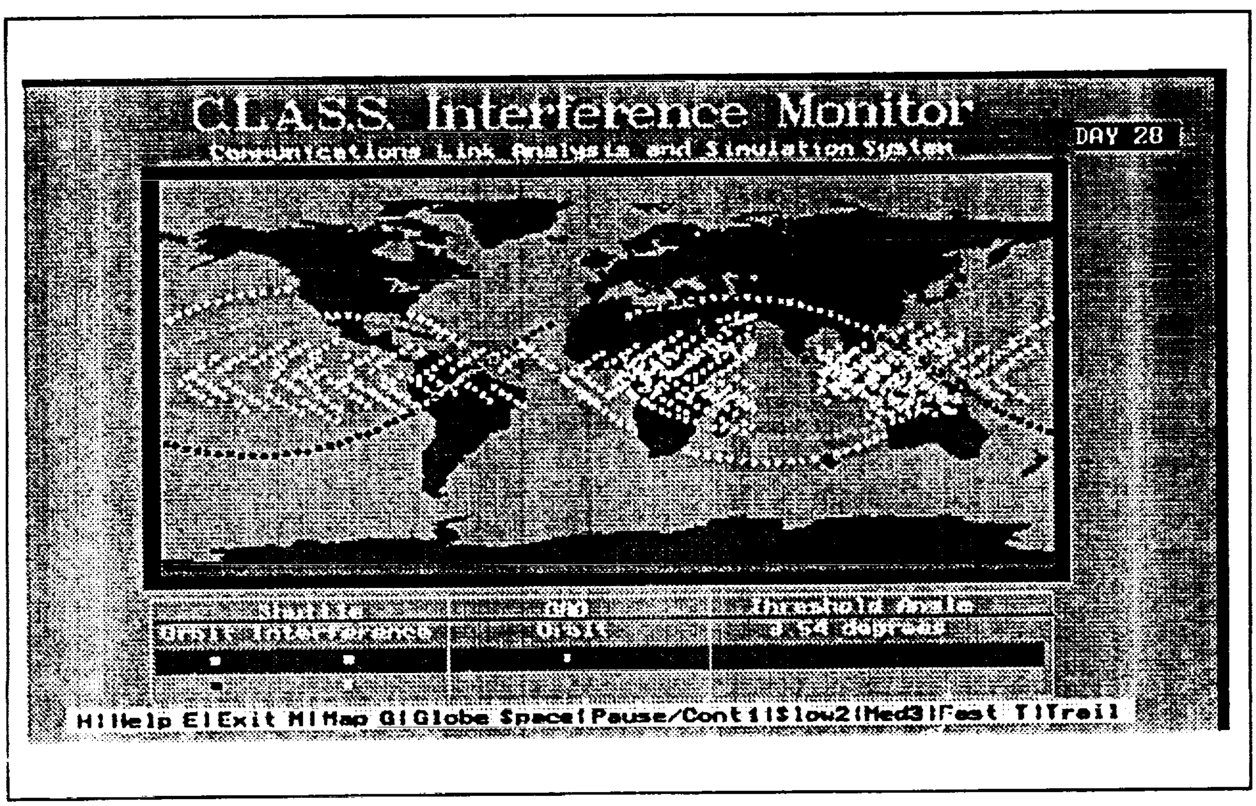


Figure 7. IM Interactive Graphics Screen

spacecraft. IM is used by NASA GSFC for many projects: for network and mission planning and as an aid for both frequency and polarization allocation. NASA headquarters has employed IM for a user spacecraft loading study to help determine network and mission plans for TDRS II user spacecraft. IM is also frequently used by the Space Network Interoperability Panel (SNIP) to study possible interoperability scenarios between the relay satellite systems of NASA, the Japanese Space Agency (NASDA) and the European Space Agency (ESA.) The ease of use and flexibility of IM enables NASA to efficiently determine optimal satellite configurations for the Space Network of the twenty first century.

REFERENCE

[1] T. Kaplan, J Freedman, D. Wampler, A. Musliner, C. Ruseau, "CLASS Interference Analysis System," Proceedings IEEE National Telesystems Conference, Washington D.C., May 1992, pp. 12-1 - 12-7.

SESSION 5: TELECOMMUNICATIONS ENGINEERING