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S-Band and Ku-Band Return Service Interference Between TDRSS Users

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Abstract

The Tracking Data Relay Satellite System (TDRSS) return service performance can be degraded by interference from another user when two or more spacecraft communicate with the same Tracking Data Relay Satellite (TDRS) at the same time. This paper describes the S-band and Ku-band return service self-interference environment expected in the 1996 - 2010 timeframe and shows the self-interference expected for selected TDRSS users based on Communications Link Analysis and Simulation System (CLASS) Automated Conflict Resolution System (ACRS) and Interference Monitor (IM) tools. The results show:

a. which user links are susceptible to interference from other users,
b. the interference statistics,
c. whether or not interference can be avoided with appropriate interference mitigation techniques such as scheduling, cross-polarization, or Pseudorandom Noise (PN) spreading.

The analysis results enable Space Network (SN) managers to determine the impacts of self-interference on the TDRSS service availability. They also enable project offices to determine whether they should (a) select return service communications parameters, such as polarization and PN spreading, to minimize the probability of being impacted by self-interference, (b) try to schedule TDRSS support around other user spacecraft communications schedules, or (c) accept communication outages due to self-interference.

1.0 Analysis Approach

This analysis uses the CLASS ACRS [1, 2] and IM [1] software packages to assess the return link performance for selected TDRSS users in the presence of self-interference. The selected TDRSS users are Space Transportation System (STS), Bilateration Transponder System (BRTS), Earth Observing System (EOS), Extreme Ultraviolet Explorer (EUVE), Gamma Ray Observatory (GRO), Hubble Space Telescope (HST), Space Station Freedom (SSF), and Ocean Topography Experiment (TOPEX).

ACRS is an interference prediction tool designed to analyze communications problems arising from two or more spacecraft transmitting return links to the same TDRS simultaneously. ACRS is used in this analysis to calculate interference threshold angles. The interference threshold angle is the angle at the TDRS antenna formed by the vectors from the TDRS to each of the users as shown in Figure 1. It is defined as the minimum angle that provides sufficient antenna discrimination to ensure that the desired link achieves a 10^{-5} Bit Error Rate (BER) (10^{-4} for some STS links) in the presence of interference from another user. ACRS also provides BER performance curves as a function of interference levels which are useful in assessing why interference occurs between users.

IM is a software tool that calculates interference statistics between TDRSS users for a given interference threshold angle. The statistics include the percentage of time that interference occurs on average and in a worst-case week. IM predicts the orbital trajectory of two users over a 25-year period and calculates the probability of interference between these users for a given interference threshold angle. It assumes that both users communicate continuously and interference occurs whenever the angle formed by the vectors from the

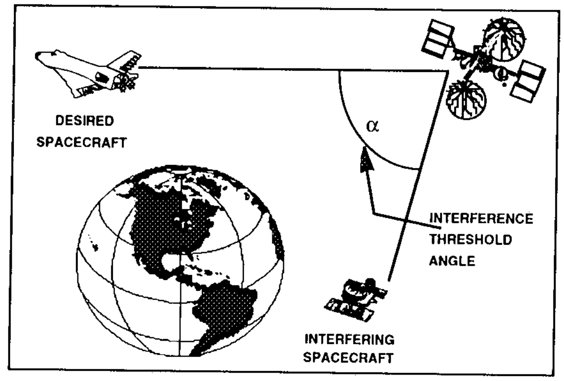

Figure 1. Interference Threshold Angle

TDRS antenna to each of the users is less than the given interference threshold angle. (The statistics do not consider passage through the Zone of Exclusion (ZOE).)

Figure 2 shows a block diagram of the interference analysis approach.

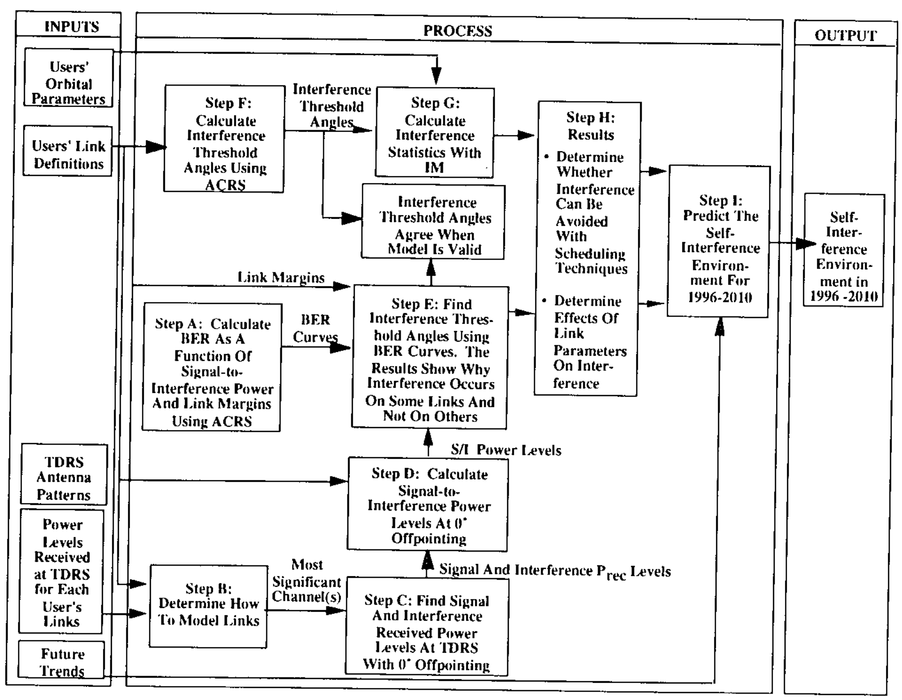

Figure 2. Analysis Approach

2.0 S-band Interference Analysis

There are 48 unique S-band links considered in this analysis. ACRS software can calculate the interference threshold angle for all possible combinations of desired and interfering links. However, one of the objectives of this analysis is to explain why some link combinations are not susceptible to interference (i.e. the interference threshold angle is zero) and other links require large offpointing angles (i.e. a large interference threshold angle). This is done with the use of BER curves that are plotted as a function of the signal-to-interference power ratio. It is desirable to show the link BER performance for all possible interfering and desired link combinations with a minimum number of curves. [3] has found that each link considered in this analysis can be modeled as a Binary Phase Shift Key (BPSK) signal, without loss of accuracy. This reduces the number of BER curves needed in the analysis.

2.1 TDRS Antenna Discrimination

This analysis uses the antenna patterns defined in [4] and [5], which are shown in Figures 3 and 4.

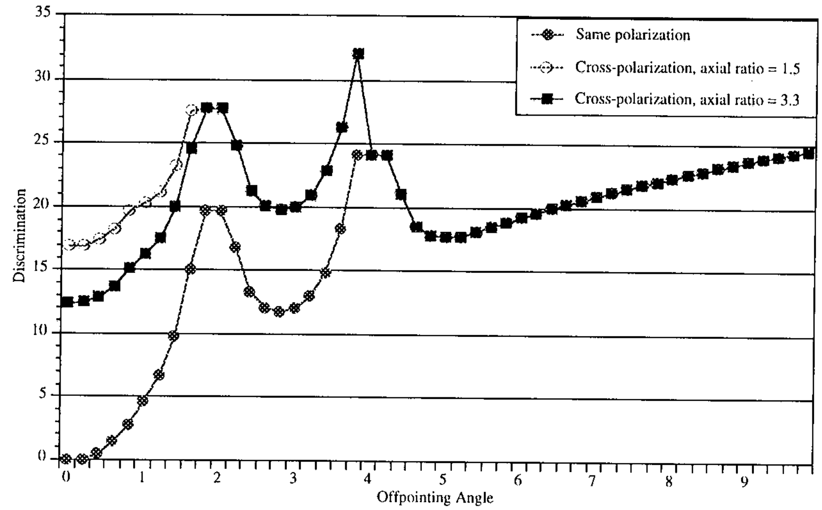

Figure 3. SSA Antenna Discrimination

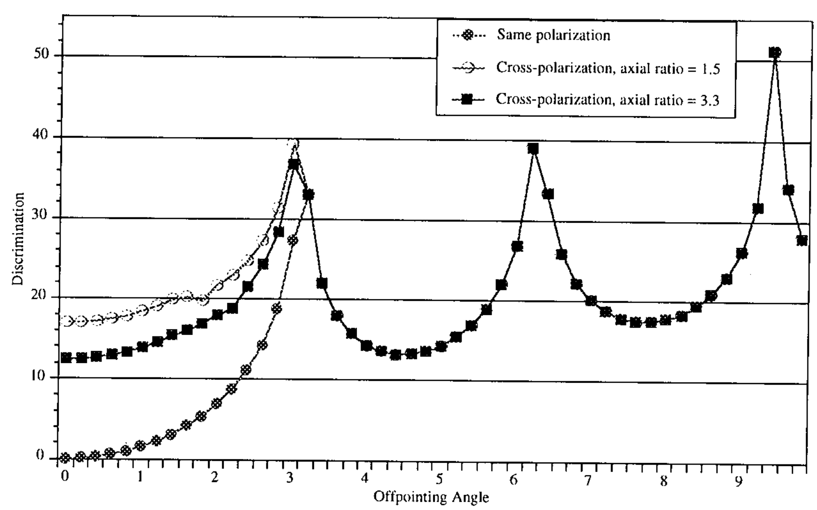

Figure 4. SMA Antenna Discrimination

2.2 BER Performance in the Presence of Self-Interference

The following indicators determine the BER of the desired link in the presence of an interfering link when both users operate at the same frequency:

a. Received power level of the interfering signal relative to the desired signal.
b. Symbol rate of the interfering link as compared with the desired link.
c. Link margin of the desired link.

2.2.1 Performance of Nonspread Links

Figures 5 and 6 show the BER performance of nonspread links for different combinations of desired signal symbol rates relative to interfering signal symbol rates and different signal margins. These figures also have arrows pointing to the BER at 0° offpointing for several interfering and desired user link combinations. (The links are defined in [3].) The interference threshold angle is also shown for each combination.

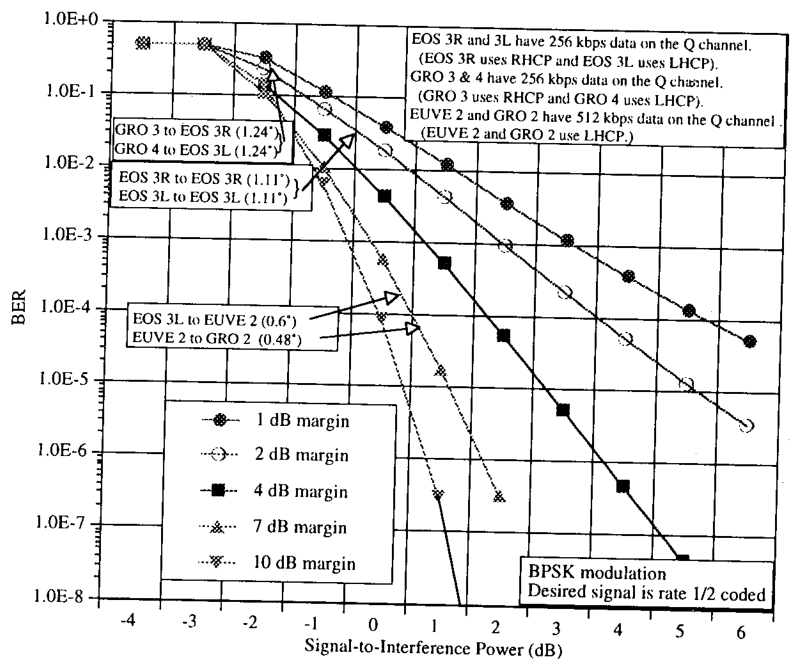

Figure 5. Performance of Nonspread Links Due to Interference When the Desired Symbol Rate is ≥ the Interfering Link Symbol Rate

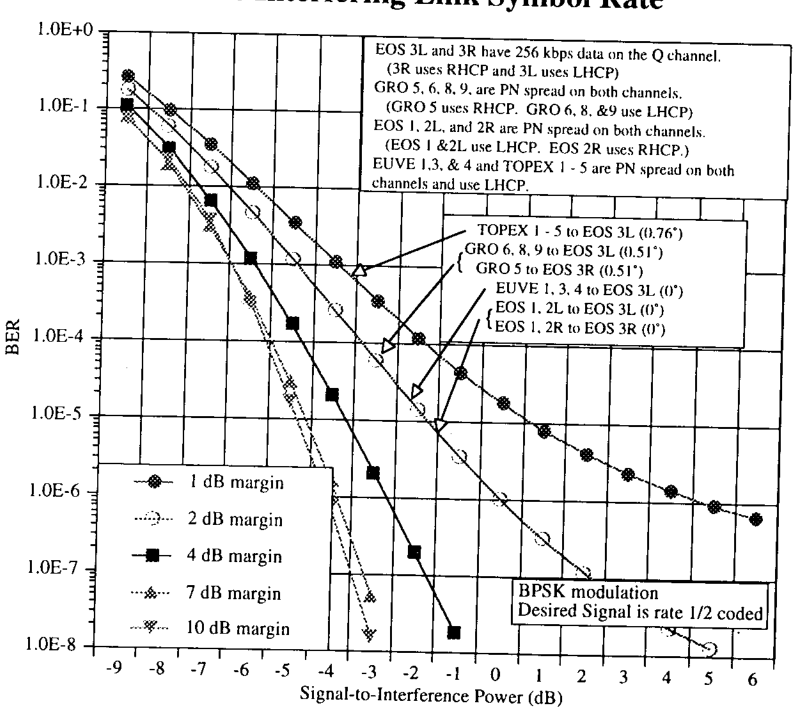

Figure 6. Performance of 256 kbps Nonspread Links With Interference from a PN Spread Link

Figures 5 and 6 show that there are three ways to improve the BER performance when the desired user's link is nonspread:

a. Decrease the symbol rate of the desired signal relative to the interfering signal. Reducing the symbol rate of the desired signal reduces the desired signal bandwidth, which means that more of the interferer's power is filtered in the receiver. A comparison of Figures 5 (desired signal rate to interfering symbol rate ≥ 1) and 6 (desired signal rate to interfering symbol rate ≈ 1/6) shows the effect that this filtering has on the BER performance.
b. Increase the desired user's signal margin. This improves performance because increasing the user's signal margin reduces the sensitivity of the signal to noise.
c. Increase the Signal-to-Interference power ratio.

2.2.2 Performance of PN Spread Links

The performance of PN spread links depends on the desired user's data rate and signal margin. It does not depend on the symbol rate of the interferer since the interfering signal has a symbol rate equal to 3 Mcps after the PN despreader. Figure 7 shows the BER performance of PN spread links for various data rates and signal margins on the desired link. This figure also has arrows pointing to the BER at 0° offpointing for several interfering and desired user link combinations. The interference threshold angle calculated by ACRS is also shown in parenthesis for each combination.

Figure 7 shows that there are three ways to improve the BER performance when the desired user's link is PN spread:

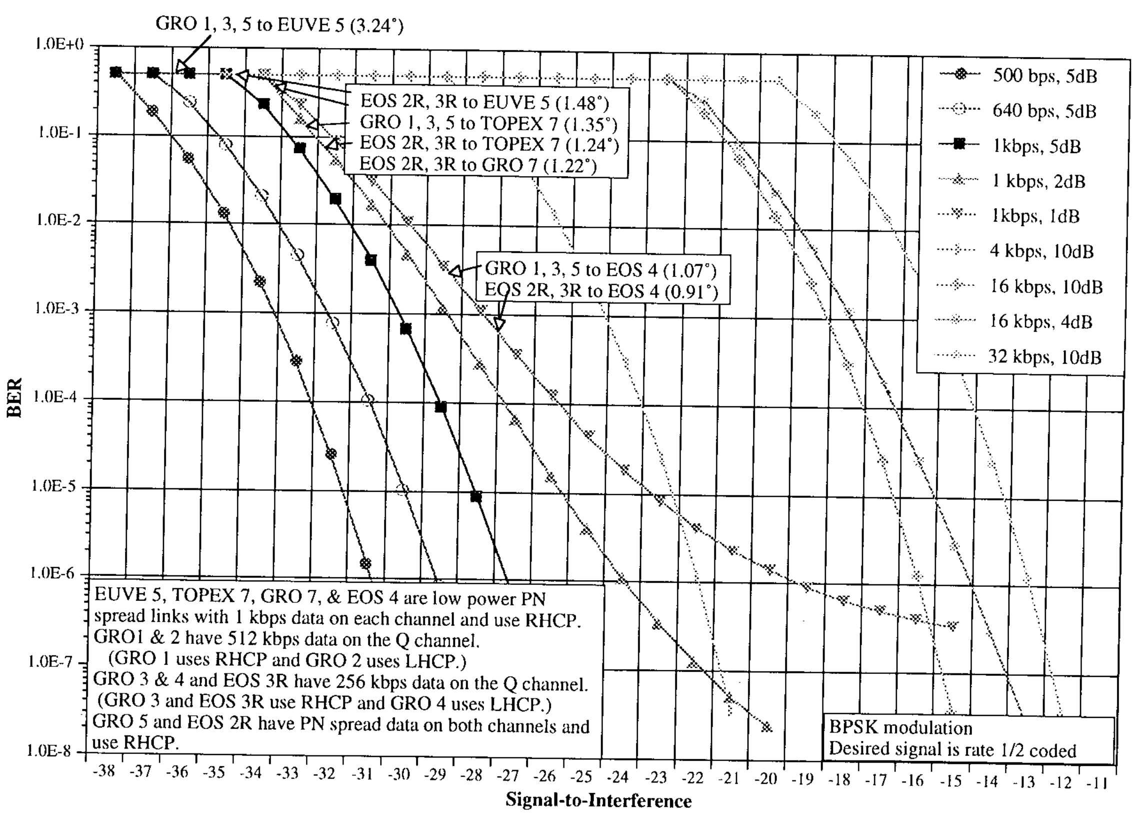

Figure 7. Performance of PN Spread Links in the Presence of Interference

a. Decrease the data rate of the desired signal. At the receiver, despreading the desired signal spreads the interfering signal. Therefore, the interfering signal's symbol rate in the receiver is the chip rate of the desired PN spread signal, 3 Mcps, and the interfering signal's received bandwidth is 6 MHz. Reducing the data rate of the desired signal reduces the desired signal bandwidth, which means that more of the interferer's power is filtered in the receiver.
b. Increase the desired user's signal margin.
c. Increase the Signal-to-Interference power ratio.

2.2.3 Performance of STS Links

Figure 8 shows the BER performance of the 192 kbps STS link for various data rates on the interfering link. This figure also has arrows pointing to the BER at 0° offpointing for several interfering and desired user link combinations. The interference threshold angle calculated by ACRS is also shown in parenthesis for each combination.

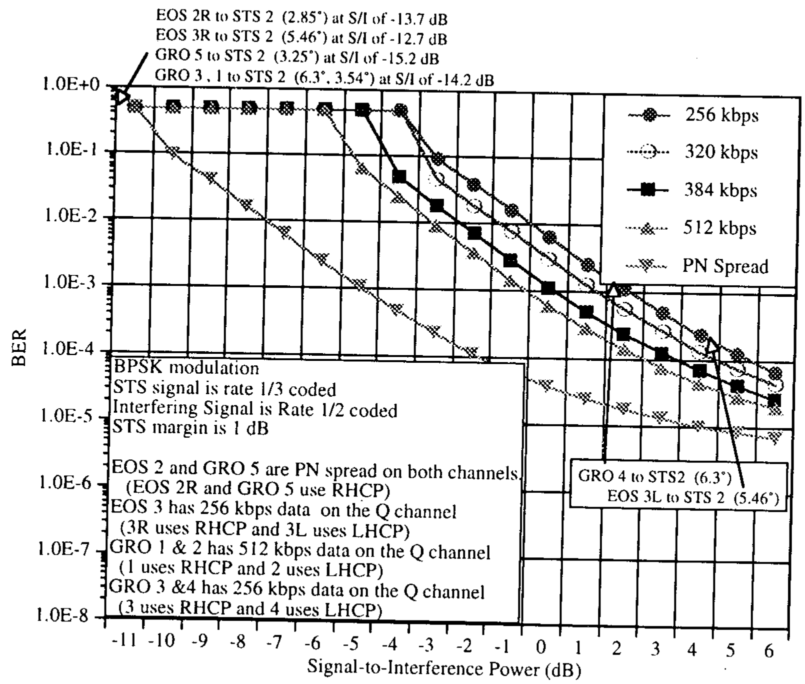

Figure 8. Performance of the STS 192 kbps Link in the Presence of Interference

2.3 Links that are Susceptible to Interference

ACRS results show that:

a. Interference only affects the 2287.5 MHz S-band Single Access (SSA) links. The S-band Multiple Access (SMA) links are not susceptible to interference due to PN spreading.
b. STS links are very susceptible to interference from other users' links via the High Gain Antenna (HGA) even if the other user is cross-polarized. This is because the STS signal is nonspread, STS power levels received at the TDRS are very low relative to other USAT HGA links, and STS signals have very low signal margins.
c. The majority of self-interference occurs when the desired signal is nonspread and both the desired user and the interferer transmit on the HGA with the same polarization.

d. Low power omni links with Right Hand Circular Polarization (RHCP) are susceptible to interference from GRO and EOS if these two users transmit on the HGA antenna with RHCP.
e. EUVE's low power omni link is susceptible to interference from HST if HST transmits on 2287.5 MHz with the HGA antenna, even though EUVE link 5 and HST links are cross-polarized. This is because EUVE omni link has insufficient margin (-1 dB) and HST has the highest transmit power of all the users considered.

2.4 Self-Interference Statistics

IM simulations show that most of the interference between any two users at a time occurs less than 1.2% of the time on average or 7% of the time in a worst case week. There are only five link combinations which experience interference more often than this. Interference to STS from GRO, another STS, TOPEX and EOS can occur up to 80%, 20%, 17%, and 10% (respectively) of the time in a worst-case week and up to 14.9%, 1%, 10.8%, and 7.5% (respectively) on average. Interference to EUVE from GRO can occur up to 15% in a worst-case week and 6.1% on average.

2.5 Interference Mitigation Techniques

2.5.1 PN Spreading

A comparison of Figure 7 with Figures 5 and 6 shows that the signal-to-interference ratio required to achieve a 10^{-5} BER is much lower for PN spread signals than for nonspread signals. Therefore, PN spreading is a very effective mitigation technique. In fact, none of the PN spread signals transmitted via the HGA are susceptible to interference. However, the PN spread signals transmitted via the omni antenna are susceptible to interference from other users unless the interfering signal is cross-polarized.

2.5.2 Cross-Polarization Discrimination

We define the interference attenuation needed as the difference between the signal-to-interference ratio needed to achieve a 10^{-5} BER (10^{-4} for STS) and the signal-to-interference ratio with 0° offpointing. Consider the case where low levels (<11.8 dB for SSA return signals and < 12.4 dB for SMA return signals) of interference attenuation is needed. Figures 2 and 3 show that this attenuation is achieved at all offpointing angles if the signals are cross-polarized. Therefore cross-polarization is an effective interference mitigation technique when low levels of attenuation are needed. Figures 2 and 3 also show that high levels (greater than 17.8 dB for SSA return signals and 13.1 dB for SMA return signals) of interference attenuation can only be achieved at large offpointing angles where the antenna discrimination of cross-polarized signals is the same as for signals that use the same polarization. Therefore, the cross-polarization discrimination is not helpful in mitigating the interference when large interference attenuation levels are needed.

2.5.3 Scheduling

Each user transmits several links and only some of these links receive interference from and cause interference to other TDRSS users. Interference between users can be minimized if users avoid transmitting on the links that interfere with each other at the same time (whenever the angle at the TDRS formed by the vectors pointing to each user is less than the interference threshold angle). For example, GRO and EOS can both transmit with RHCP and Left Hand Circular Polarization (LHCP) polarization. Interference between these users can be avoided if GRO and EOS use opposite polarization when the angle at the TDRS is less than the interference threshold angle.

A single TDRS can support five SMA users and 2 SSA users. SMA links do not receive interference due to PN spreading. The problem is that each SSA user can receive interference from the remaining six users. It could be difficult to avoid interference by selecting links and scheduling support times for all 7 users all the time.

2.6 Self-Interference Environment for 1996 - 2010

All the self-interference events occurring on the 2287.5 MHz SSA links considered in this analysis fall into one of the following three categories:

a. STS links. These links are very susceptible to interference from other user's HGA links even if the interferer is cross-polarized and/or uses PN spreading.
b. Nonspread links. The majority of self-interference occurs when the desired signal is nonspread (Q channel of mode DG1-3) and both the desired user and the interferer transmit on the HGA and with the same polarization.
c. Low power omni links. These links are susceptible to interference from other user's that transmit on the HGA antenna.

Since STS is very susceptible to interference from other user's HGA links (regardless of whether the other user uses cross-polarization or PN spreading), it is likely that any new user supported by TDRSS at 2287.5 MHz will interfere with STS.

Nonspread signals are required for tape recorder dumps and many users require them. It is likely that these nonspread links operating at 2287.5 MHz will receive interference from other user's links and will cause interference to other user's links.

PN spread low power omni links are only used for backup and contigencies. Due to the fact that they are used infrequently or in emergency situations, it is expected that the interference to these links can be avoided by scheduling.

Therefore, there are two areas of concern for S-band self-interference in 1996 - 2010 as the number of TDRSS users increases. First is the likelihood of interference to STS. Second is the possibility of interference to all the nonspread links from any of the other user's HGA links.

3.0 Ku-Band Interference Analysis

The analysis approach at Ku-band is the same as at S-band with the only exception being with regards to how the links were modeled. The S-band analysis considered 48 links. In order to show the link performance in the presence of self-interference for all possible interfering and desired link combinations with a minimum number of BER curves, the S-band analysis modeled links with BPSK signals. This was not necessary for the Ku-band analysis since the Ku-band analysis only considers four Ku-band links: two STS links, one EOS link, and one SSF link.

3.1 TDRS Antenna Discrimination

This analysis uses the antenna pattern in the CLASS database which was obtained from [4] and is shown in Figure 9.

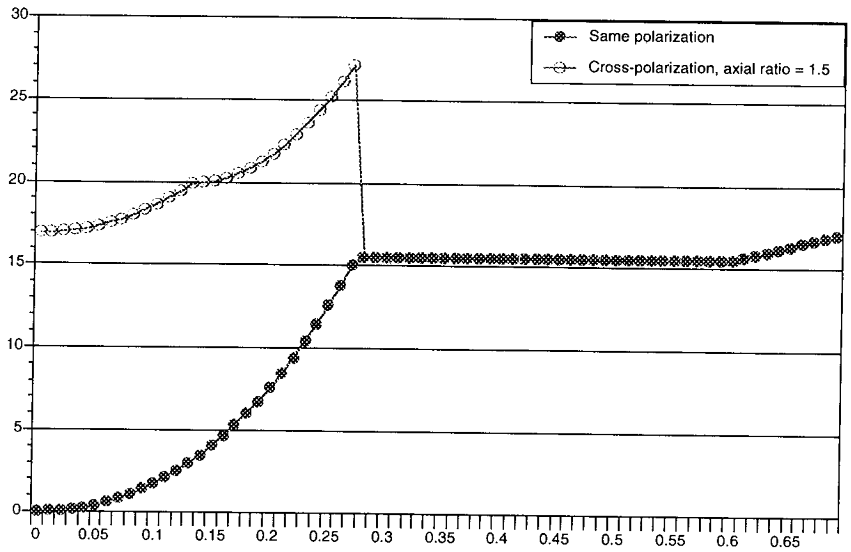

Figure 9. KSA Antenna Discrimination

3.2 STS, SSF, and EOS Link Polarizations

STS Ku-band links are RHCP, the SSF Ku-band link is LHCP, and the EOS link is either RHCP or LHCP. (EOS links 5R and 5L represent the EOS links with RHCP and LHCP, respectively, in the BER curves shown in Section 3.3.)

3.3 BER Performance in the Presence of Self-Interference

3.3.1 Performance of STS Links

Figure 10 shows the performance of the STS channels in the presence of interference from EOS. This figure also has arrows pointing to the BER at 0° offpointing showing the interference from the EOS Ku-band link with RHCP. Figure 10 shows that STS channels 2 and 3 experience interference in the presence of this EOS link. None of the STS channels is susceptible to interference from an EOS signal with LHCP since the cross-polarization discrimination ensures that the signal-to-interference power is greater than -1 dB, which is sufficient to achieve a 10^{-5} BER (10^{-4} for the STS channel 1).

3.3.2 Performance of EOS Links

The EOS Ku-band link has the highest symbol rate of all the Ku-band links, except for Shuttle Channel 3 with 50 kbps data. Figure 11 shows the performance of the EOS link for the two cases: first, when the EOS symbol rate is greater than or equal to the interfering signal's symbol rate; and second, when the interfering signal is the STS channel 3 with 50 kbps data. This figure also has arrows pointing to the BER at 0° offpointing showing the interference from the other users. It shows that EOS links can receive interference from STS, SSF and another EOS even if the other user is cross-polarized. This is because the EOS signal has the highest symbol rate and a very low signal margin, and because the EOS power level received at the TDRS is low relative to the other USAT power levels. The cross-polarization discrimination is insufficient to mitigate interference from STS and SSF because the antenna discrimination required to achieve a 10^{-5} BER is only available at large offpointing angles, where there is no cross-polarization discrimination. (See Figure 9).

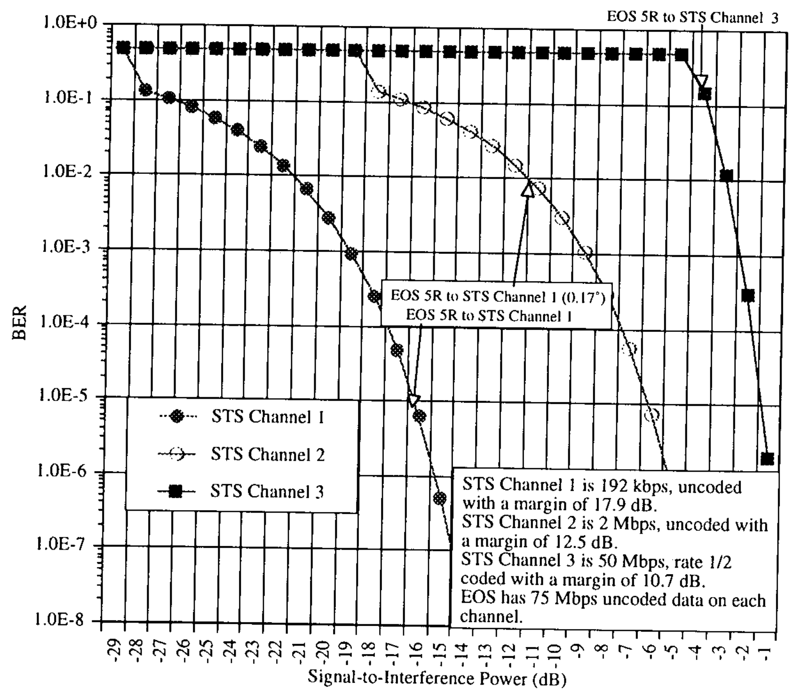

Figure 10. Performance of STS Ku-band Links in the Presence of Interference from EOS

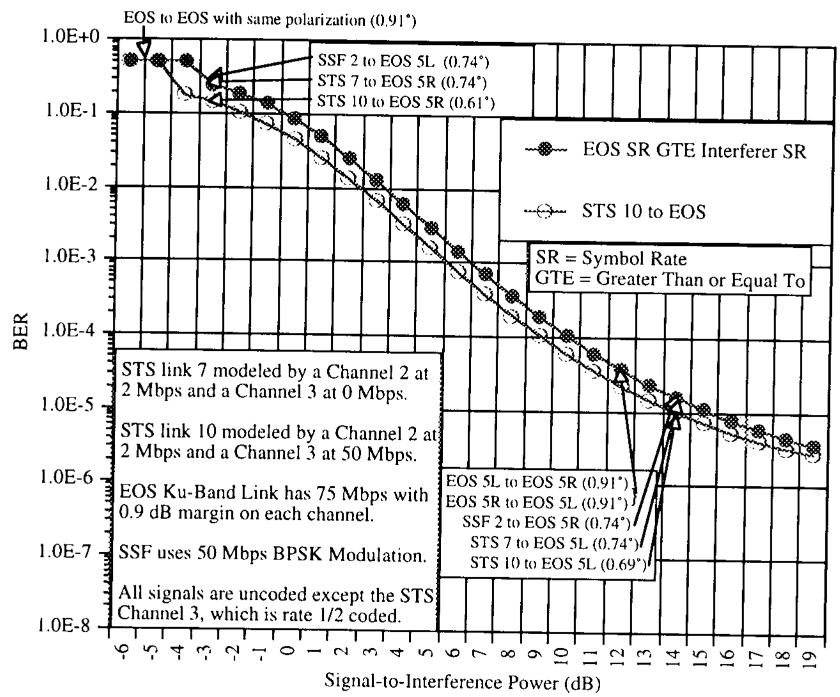

Figure 11. Performance of EOS Ku-band Links in the Presence of Interference from STS and SSF

3.3.3 Performance of SSF Links

The SSF Ku-band link has a higher symbol rate than the other Ku-band links, except for Shuttle channel 3 with 50 kbps data and the EOS link. Figure 12 shows the performance of the SSF link for the three cases:

first, when the SSF symbol rate is greater than the interfering signal's symbol rate; second, when the interfering link includes STS channel 3 with 50 kbps data; and third, when the interfering link is the EOS link. This figure shows that only the EOS link with LHCP can interfere with SSF communications. This is because both users transmit similar symbol rates, the SSF power level received at the TDRS is low relative to the EOS power level and the SSF signal has a very low signal margin. Both STS and the EOS link with RHCP cannot interfere with SSF communications because these links are cross-polarized providing a signal-to-interference power that is greater than 13 dB and a BER less than 10^{-5}.

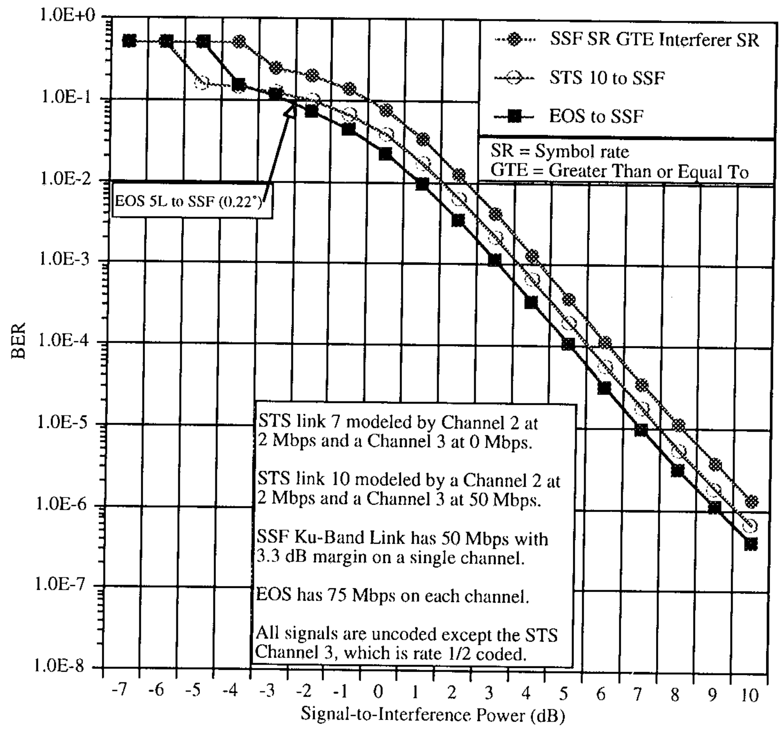

Figure 12. Performance of SSF Ku-band Links in the Presence of Interference from STS and EOS

3.4 Results

Section 3.3 and [3] shows that:

a. Cross-polarization discrimination is sufficient to ensure that STS and SSF do not interfere with each other.
b. EOS links can receive interference from either STS link, the EOS link, or the SSF link even if the other link is cross-polarized. The cross-polarization discrimination is ineffective in mitigating interference to EOS.
c. Both STS links can interfere with each other.
d. The EOS link with RHCP can interfere with both STS links, but the EOS link with LHCP cannot.
e. The EOS link with LHCP can interfere with the SSF link, but the EOS link with RHCP cannot.

3.5 Self-Interference Statistics

IM simulations provide the interference statistics between STS, SSF, and EOS. The results show that interference occurs less than 0.8% of the time on average but can occur up to 3% of the time in a worst-case week. These averages are significantly lower than the averages obtained for S-band interference primarily because the Ku-band antenna pattern has a much narrower beamwidth than the S-band antenna pattern.

3.6 Interference Mitigation Techniques

The only interference mitigation techniques that are available in the current system is cross-polarization and scheduling. Cross-polarization is very effective, but it is not able to mitigate interference from any of the users to an EOS spacecraft since EOS has the highest symbol rate and lowest power of the three users. Fortunately, each TDRS can only support two users at a time and the percentage of time that interference occurs is small due to the small beamwidths at Ku-Band. Therefore, scheduling should be sufficient to avoid interference with one exception. The most serious concern is when two or more STS spacecraft are in orbit. Each STS spacecraft may require 100% coverage when not in ZOE, but there is no way to avoid interference between two STS spacecraft since both of the STS links interfere with each other. It should also be noted that since STS and SSF require 100% coverage when not in ZOE and both of these users have a higher priority than EOS, EOS communications must be scheduled to avoid interference with STS, SSF, and other EOS spacecraft. This, however, should be achievable as EOS only requires 20 minutes of service every orbit, and it can use LHCP to avoid interfering with STS and RHCP polarization to avoid interfering with SSF.

[6] provides an example showing how interference to STS can be avoided with scheduling.

3.7 Self-Interference Environment for 1996 - 2010

It is anticipated that more and more users will be using the Ku-Band service. However, it should be possible to avoid interference by scheduling support times since each TDRS only supports two users at a time.

4.0 Conclusions

The S-band analysis showed that the percentage of time that interference occurs between any two users is less than 1.2% on average and 7% in a worst-case week most of the time. However, there are some cases where interference occurs up to 15% of the time on average and 80% in a worst-case week.

Interference at S-band can be avoided with appropriate scheduling techniques. However, this can become more difficult with many users. Furthermore, self-interference events at S-band can be expected to increase in the future as data rates increase. There are two areas of concern for self-interference in 1996 - 2010. First is the likelihood of interference to STS. Second is the possibility of interference to all the nonspread links from any of the other user's HGA links.

The Ku-band analysis showed that the percentage of time that interference occurs between any two users is less than 0.8% on average and 3% in a worst-case week. Since each TDRS only supports two Ku-band users at a time, it should be possible to avoid interference with appropriate scheduling techniques.

5.0 Acknowledgements

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6.0 References

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