# Channel Capacity Simulation of Peer-to-Peer Spread Spectrum Satellite Transponders.

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## Abstract

A spread spectrum transponder for the International Space Station has been proposed, the goal of which is to provide medium to high bit rate digital communications to radio amateurs. In order to help predict the capabilities of such a system, as well as aid in its design , a simulation of system bit error rates has been performed. The simulation is performed at the channel symbol ("chip") level, using a freely available communications system simulator package. The results of these simulations show that over a hundred users may participate in digital voice communications at a time using the transponder.

## 1 Introduction

The Spread Spectrum Wideband T!ransponder[ l] (SSWBT) is designed to be a payload on the EXPRESS Pallet of the International Space Station (ISS). The SSWBT is currently in the proposal stage. Its goals are to simultaneously provide:

- Low cost digital voice communications
- Digital Videoconferencing
- High bitrate, low-latency data transfer
- Development of Sp:read Spectrum technology in the amateur community

One of the greatest features of the SSWBT concept is that while more complex and expensive systems with high power and gain will be necessary to transmit at the higher bitrates, nothing extra will be necessary to receive these transmissions. Thus, the low bandwidth systems, besides being useful for voice communications between comparable users, can be effectively used for such applications as web browsing, and file retrieval. Ten kilobits per second is plenty of bandwidth for requesting web pages, which would be served by the medium or high bandwidth systems. Highly asymmetric links are very useful for these applications

## 2 SSWBT Design

### 2.1 Features

- Direct Sequence Spread Spectrum (DSSS) Modulation
- 2.4 GHz Band Uplink

- 5.7 GHz Band Downlink

a 5-10 MHz wide signal bandwidth

- Automatic Power Control

- Scalable bitrate

## 2.2 Capabilities

This system will be able to accommodate over 100 simultaneous digital voice users, several high bitrate video conferencing sessions, and a high-bandwidth data link, all at once. Stations within 400 miles of the point directly below the ISS will be able to access these facilities, providing a coverage area of about half a million square miles. It can provide high data rate, asymmetric data links to small mobile users, with tiny patch antennas. User systems will have low power consumption.

## 2.3 General Architecture

In order to receive and demodulate SS signals from hundreds of users at one time, hundreds of demodulators would be necessary on the ISS. Instead, the SSWBT simply amplifies and retransmits the signals which it receives. This allows the ground stations to each pick out and demodulate their own signals. A key advantage of the SSWBT is its very simple space segment. The payload will consist of a linear transponder, and a simple "carrier" signal generator, which will actually generate a known SS signal. All of the complexity will be in the ground stations. This allows for easy changes to the modulation format, and avoids the need for complex and expensive radiation-hardened DSP components.

### 2.3.1 Modulation and Coding

DSSS Modulation will be used, with binary phase-shift keying (BPSK). Whatever the bit rate which a station is transmitting at, it will always use the same chipping rate. Thus, all signals will have the same occupied bandwidth, and processing gain will be inversely proportional to bit rate. Effective radiated power will be in direct proportion to bit rate, so that energy per bit is constant for all stations.

Different spreading codes correspond different "channels" of communications. Each station will have an assigned "hailing code," to which it will always be listening. When station A wishes to transmit to station B, station A will transmit using B's hailing code. In this first packet, A will send a code pair, one for a to use when talking to B, one for the reverse link.

In order to provide more reliable communications, with lower power, and higher user capacity, forward error correction (FEC) will be used extensively. The most likely candidate is Convolutional coding and Viterbi decoding. ASICs are commonly available now which are capable of high data rates with rate l/2, and l/3 codes and constraint lengths of 7 or 9. Other options might include combining convolutional codes with Reed-Solomon codes, or even using turbo codes. Again, these are all issues for the ground stations, and so could be changed without touching the transponder. Multiple schemes could be used concurrently, allowing experimentation to coexist with normal use.

### 2.3.2 Automatic Power Control

Automatic power control (APC) is necessary to make this system work. Without it, stations closer to the satellite would swamp out the ones further away.

APC guarantees that all signals will be received at the same strength, maximizing the number of them that can be decoded successfully. The pilot signal will be used as the reference power level. When a station is transmitting, it must constantly adjust its power up or down to make its downlink signal equal in power to the pilot signal. The actual downlink power received will vary, but the relative levels of the many signals and the pilot signal will remain the same.

#### 2.3.3 Space Segment

The space module, the SSWBT itself, is a simple linear transponder, with only one addition. A simple (and small) circularly polarized patch antenna receives the many uplink signals at 2.4 GHz. After being amplified and filtered, they are downconverted to IF. At IF, the signal passes through a channel-bandwidth filter, and an AGC amplifier. Then a pilot signal is injected, and the combined signal is upconverted to 5.7 GHz. After it is amplified (about 25W output), it is retransmitted back to earth via another circularly polarized patch antenna.

The pilot signal is very crucial to the operation of the system as a whole. It allows the ground stations to have a reference power so that they are able to provide near perfect power control. It also provides a signal timing and doppler reference which the ground stations can al.so use to ease the problem of getting code and dat a synchroni.zation.

#### 2.3.4 Ground Segment

A minimal ground station, capable of transmitting digital voice, will be the typical end-user system. Such a station will use circularly polarized patch antennas, just like the satellite. It must have at least three despreading channels. One to monitor the pilot signal, one to monitor the station's own transmitted power and timing, and one for useful reception of signals from other stations. Since all of the signal processing associated with despreading channels will be done in digital logic in FPGAs or ASICs, adding more will not be difficult. Additional ch annels will be useful for receiving many datastreams at once.

## 3 Simulation

The SSWBT/ground station system was extensively simulated using the GOSSIP[5] simulation environment. GOSSIP is free software, available under the terms of the GPL, which allows simulation of complex systems. Primitive building blocks are designed using a C++ API. These blocks are tied together into more complex components, and entire simulation and postprocessing systems are created using GUILE, an implementation of Scheme.

### 3.1 Implement at ion

Simulation was performed on a chip by chip basis, at baseband, as a full RF simulation would have been prohibitively slow. Nonetheless, a full model of the radio channel was used,, so accuracy should not be compromised. Traffic was modeled by random bit generators, as were the spreading codes of the stations. Channel noise is modeled as additive white Gaussian noise (AWGN) , which is a good match for line of sight satellite paths. Worst-case (in terms of dist ante) paths are assumed in all cases.

### 3.2 Limitations

Certain assumptions were made in order to simplify the simulation process. FEC was not simulated.

The receiver was assumed to have perfect synchronization with the transmitter. Doppler shift was ignored. The effects of non-ideal amplifiers and filters were ignored, as these have not yet been designed. Despreading was simulated with correlators implemented in floating point, rather than the 2-, or 3-bit digital correlators likely to be used in an actual system. Automatic power control is assumed to be perfect, so that all stations are received at the transponder (and thus the ground station) at the exact same power. Most importantly, only 10 kilobit per second (digital voice class) stations were simulated, not the higher rate stations.

### 3.3 Design Parameters

There are many design parameters of the system which need to be selected. The aim of this simulation was to aid this selection, and thus many different designs were simulated. The main variables for the simulation were:

- Uplink and Downlink frequencies (2.4, 5.7 and 1OGHz)
- Transponder Bandwidth (5 to 10 MHz)
- Transponder Model (Linear and Saturating)
- Transponder Power (25W and SOW)

Antenna gain of 6 dB on both ends of the link, and a total system noise figure of 2 dB on both ends of the link were assumed.

## 4 Simulation Results

For digital voice communications at 10 kbps, a bit error rate (BER) of 10-4 was chosen as the maximum tolerable. This is somewhat arbitrary, but is in line with figures often used in cellular phone systems. Forward error correction would be used in the system, but was not simulated, and correlation of BER with and without FEC is not always straightforward. Nevertheless, we can use a simple convolutional code for estimation purposes. The industry standard rate l/3, constraint length 7, soft decision, viterbi decoder can obtain a 10-4 BER in the same conditions in which uncoded BPSK would achieve a BER of 0.02. As any FEC system which would actually be used would be at least as good as this code, we can assume that a raw BER of 0.02 or better would indicate acceptable performance.

Besides final BER, the bit error rate for a hypothetical receiver at the transponder input is also computed (shown as “Up” in the figures). This allows us to see the relative performance of the up and down links.

A number of interesting phenomena were observed in the simulation results. Normally in SS multiple access systems, as the number of stations increases, so does the BER due to m.utual interference. While that effect is present, it is overshadowed by the power-sharing of the transponder. For example, when only one user is active, downlink power is shared by that one station’s signal and by the noise input at the transponder. When there is a large number of active users, however, that station now gets a much smaller fraction of the total downlink power. If there are 100 users, each will get less than l/lOOth of the power. Thus, the system is strongly downlink power limited, not congestion limited.

Normally, in SS systems, wider bandwidths allow for more users through higher processing gain, but have no effect on perfomance vs. random noise. However, when running through a transponder, wider bandwidths can actually hurt, because more noise will be received and retransmitted.

From the figure 1, one can see that up to 35 interferers, 5MHz wide spreading provides better results. It is not until there are about 60 interferers that 10MHz wide spreading provides a clear advantage. Unfortunately, neither system is very usable much past 60 users, at least under the assumption of the simple FEC code. Turbo codes could likely take the 1OMHz spreading well beyond that.

The 50 W, saturated power transponder is clearly inferior to the 25 W linear one (see figure 2) despite the increase in power. This can be attributed to the lack of "soft" decisions in the satellite, which usually results in the equivalent of more than a 2 dB loss. It may have fared better if even wider spreading was allowed, but that is not really practical given the current amateur space band plans.

A "reverse" band plan was also simulated, with 5.7Ghz uplink and 2.4 GHz downlink. As can be seen in figure 3, this suffers from inferior performance. The signals arriving at the transponder already have poor BER, even before retransmission.

## 5 Conclusions

The SSWBT will open up a whole new world of digital communications to the amateur radio community. By taking advantage of underutilized spectrum, and advanced communications techinques, we will finally be able to interconnect the ham world with a high bitrate, integrated network. This will open up the possibility of digital videoconferencing, digital voice communications, and high speed data transfer. The simulations have shown that very practical digital voice communications are possible with the SSWBT, for over a hundred users at a time.

The simulations performed show that a bandwidth of around 10 MHz, with a linear transponder and uplink on 2.4 GHz provides the best compromise in terms of overall BER. The system can support almost 50 simultaneous spea)kers, or over 100 simultaneous conversations when configured like this.

The simulation will be refined to include the effects of doppler shift, imperfect power control, higher bit rate (higher power) stations, and rnore rea$listic component models. Separate simulations will be performed to model acquisition and maintNenance of synchronization. Further simulation will bc performed with various forms of FEC (convolution11 coding/Viterbi decoding, concatenated with R,ctcd-Solomon codes, and possibly Turbo codes).

## References

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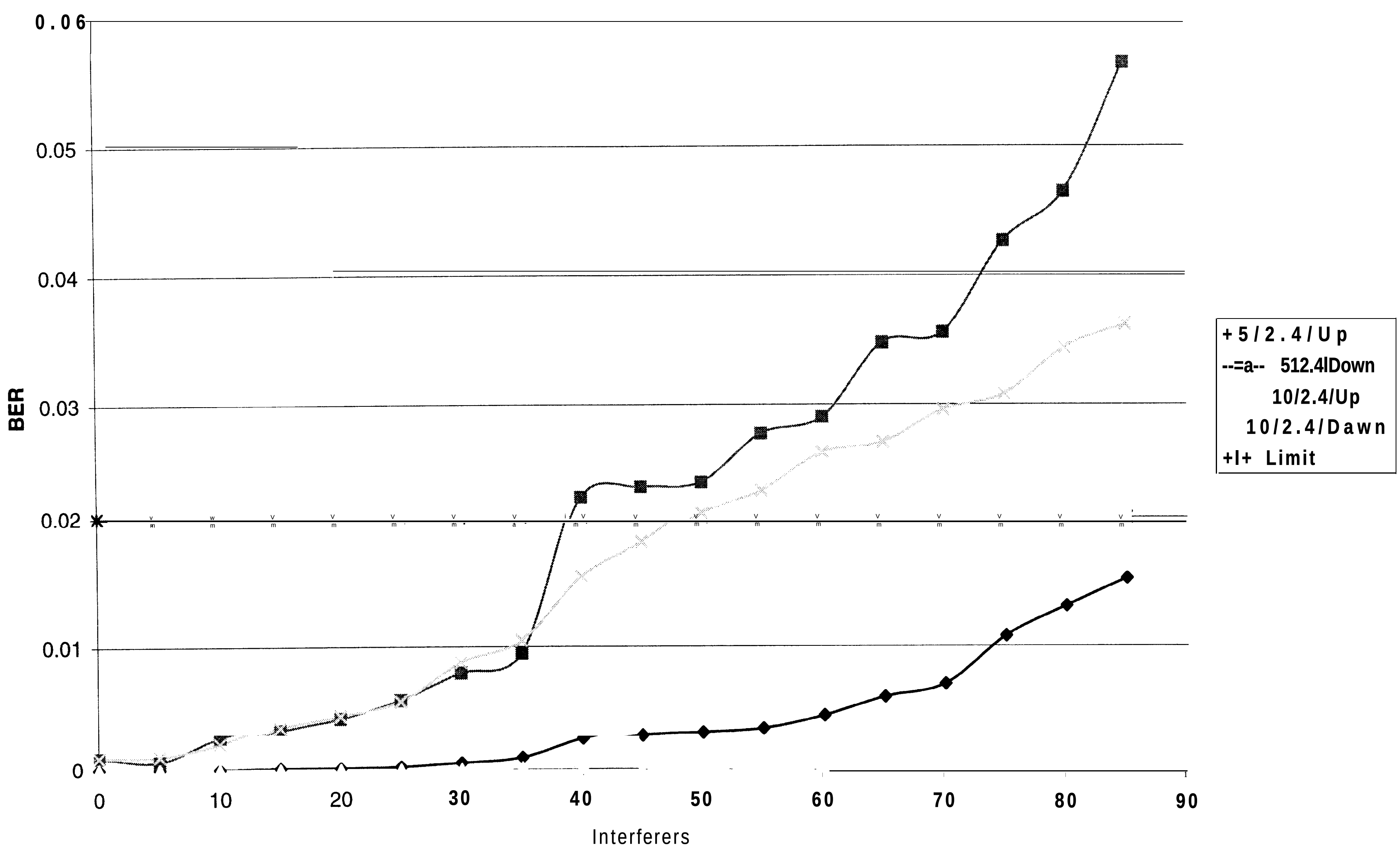
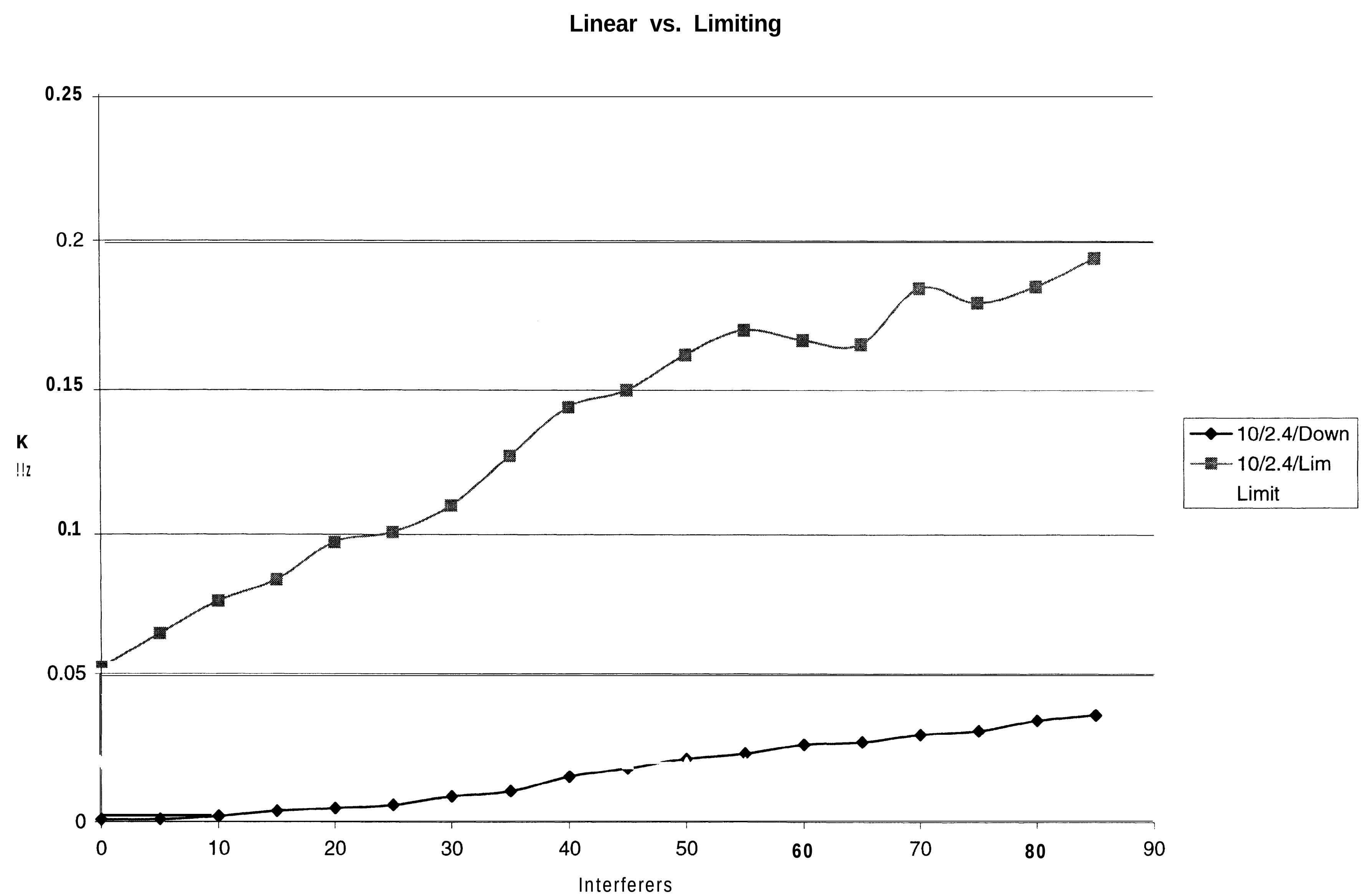
[5] GOSSIP Project Home Page. http://gossip.sourceforge.net

## Spreading Bandwidth




Linear vs. Limiting
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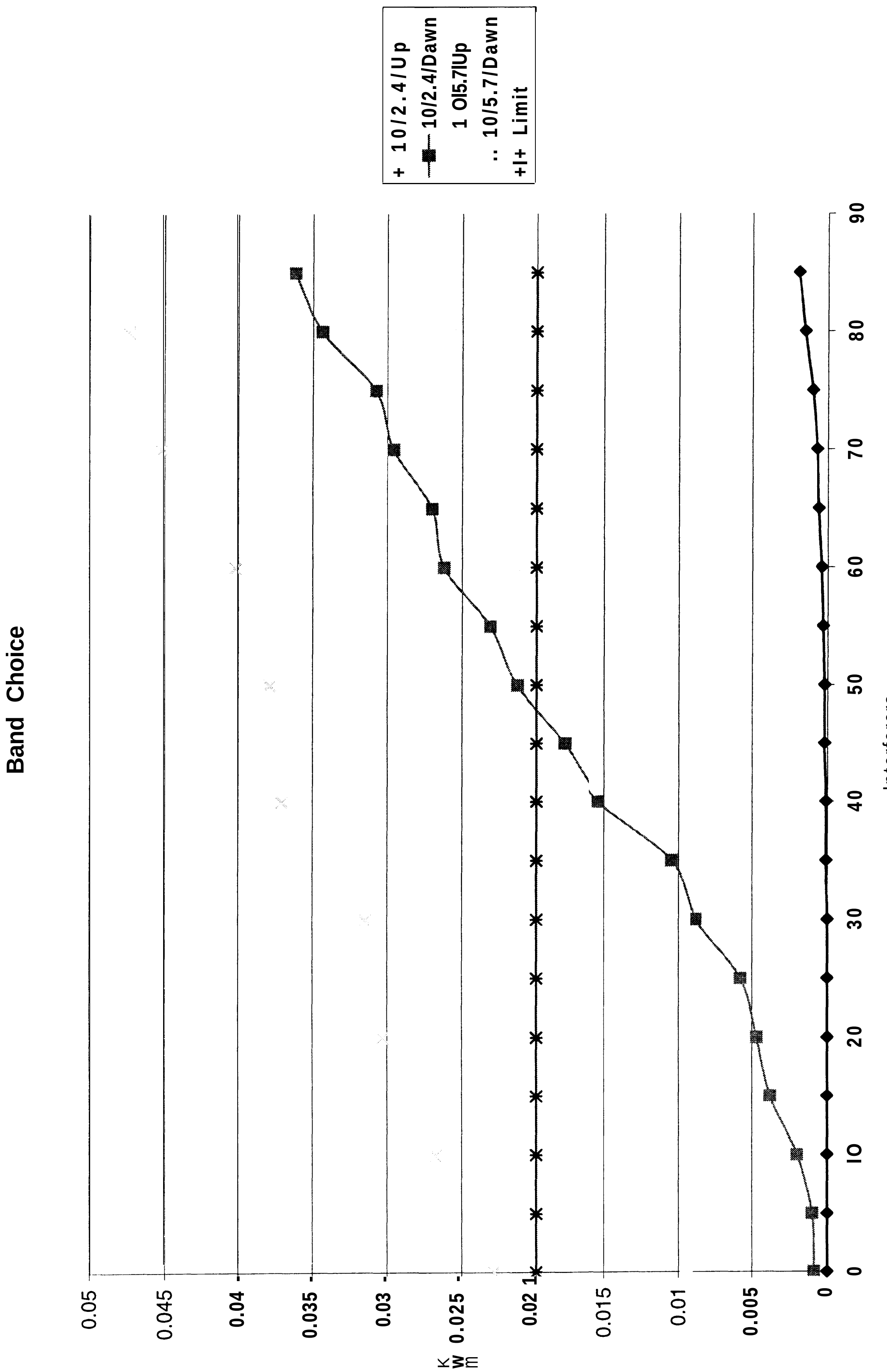

Band Choice
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.. 10/5.7/Dawn
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KWm
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