In the U.S., the incumbent primary user of the 14.0–14.5 GHz band is the FSS (Earth-to-space). In addition there are secondary allocations in various parts of the band that include Radionavigation, Land Mobile Satellite (Earth-to-space), Space Research, MS and Radio Astronomy. Internationally, the 14.0–14.3 GHz band is allocated to FSS (Earth-to-space) and Radionavigation on a primary basis and on a secondary basis to Mobile-Satellite and Space Research. The 14.3–14.4 GHz band is allocated on a primary basis to the FSS (Earth-to-space) in all three ITU Regions. In addition, in Regions 1 and 3, the MS and FS also have allocations on a primary basis. In all three Regions, there are secondary allocations to the Mobile-Satellite Service ("MSS") (Earth-to-space) and the Radionavigation-Satellite Service in this band. In the 14.4–14.5 GHz band, the primary allocations in all three ITU regions include FS, FSS (Earth-to-space) and MS, except aeronautical mobile. There are secondary allocations to the MSS (Earth-to-space), Space Research (space-to-Earth), and Radio Astronomy in portions of this band.

In the U.S., the incumbent users of the 17.3–17.7 GHz band are the FSS (Earth-to-space) on a primary basis, and Government Radiolocation on a secondary basis. In the 17.7–17.8 GHz band, the U.S. incumbent users are the FS, FSS (Earth-to-space), MS ,and FSS (space-to-Earth). Internationally, the 17.3–17.7 GHz band is allocated to the FSS (Earth-to-space) on a primary basis in all three Regions. In addition, in Region 2, the band is allocated to the BSS. The 17.7–17.8 GHz band is allocated to the FS and FSS (space-to-Earth) (Earth-to-space) in all three regions on a primary basis. In addition, in Region 2, the band is allocated to the BSS on a primary basis, and in Regions 1 and 3 to the MS on a primary basis. In Region 2, the band is allocated to the MS on a secondary basis.

In the U.S., the incumbent users of the 10.7–11.7 GHz band are the FS and FSS (space-to-Earth). Internationally, the band is allocated to the FS, MS (except aeronautical mobile), and

FSS (space-to-Earth). In addition in Region 1, the FSS allocation is also in the Earth-to-space direction. In the U.S., the incumbent users of the 11.7–12.2 GHz band are the FSS on a primary basis and the MS (except for aeronautical mobile) on a secondary basis. Internationally, the Region 2 allocation in the 11.7–12.1 GHz band is allocated to the FS and FSS (space-to-Earth) on a primary basis and MS, except for aeronautical mobile, on a secondary basis, while the 12.1–12.2 GHz band is allocated to the FSS (space-to-Earth). In Regions 1 and 3, the 11.7–12.2 GHz band is allocated to the FS, Broadcasting and BSS. In Region 3 the band is also allocated to the MS (except for aeronautical mobile) on a primary basis, while in Region 2 the MS is on a secondary basis. In the U.S., the incumbent users of the 12.2-12.7 GHz band are the BSS and FS. Internationally in Region 2 the band is allocated to FS, MS (except for aeronautical mobile), Broadcasting and BSS. In Region 1, the 12.2–12.5 GHz band is allocated to the FS, Broadcasting and BSS on primary basis and to MS, except for aeronautical mobile, on a secondary basis, while the 12.5–12.7 GHz portion of the band is allocated to the FSS (space-to-Earth) (Earth-to-space). In Region 3, the 12.2–12.5 GHz band is allocated to the FS, MS (except for aeronautical mobile), and Broadcasting, while the 12.5 – 12.7 GHz portion is allocated to FS, FSS (space-to-Earth), MS (except for aeronautical mobile), and BSS. At WRC-97, an additional primary allocation was made for NGSO FSS (space-to-Earth) systems in the 11.7–12.5 GHz band in Region 1, the 12.2–12.7 GHz band in Region 2, and the 11.7-12.2 GHz band in Region Three.

All of the Ku-band frequencies proposed for use by the VIRGO™ system were discussed at WRC-97 for NGSO FSS use. For all the bands except for the 17.3–17.8 GHz band for Region 2, provisional apfd or epfd limits were adopted. These provisional limits, as well as arrangements for possible NGSO FSS use of the 17.3-17.8 GHz band in Region 2, are the subjects of studies being conducted in the ITU by ITU-R Joint Task Group 4-9-11, which is to develop a technical report for WRC-2000 on the provisional apfd and epfd limits adopted at WRC-97. Moreover all of the bands discussed are the subject of the FCC's recently-initiated *Ku-Band* rulemaking proceeding in ET Docket No. 98-206.

3.4.1.2 C-Band Frequencies

The VIRGO™ system proposes to utilize the 5925–6725 MHz (Earth-to-space) and 3700–4200 MHz (space-to-Earth) bands.

In the U.S., the 5925–6425 MHz and the 6525-6725 MHz bands are allocated to the FS and FSS (Earth-to-space) on a co-primary basis, while the 6425-6525 MHz band is allocated to the FSS (Earth-to-space) and the MS. Internationally, in all three ITU Regions, the proposed band is allocated to FS, FSS (Earth-to-space) and MS, in addition, the 6700-6725 MHz band is also allocated to the FSS (space-to-Earth).

In the U.S., the 3700–4200 MHz band is allocated to FS and FSS (space-to-Earth) on a co-primary basis. Internationally, in Regions 2 and 3 this band is allocated to FS, FSS (space-to-Earth) and Mobile Service (MS), except for aeronautical mobile, on a primary basis. In Region 1, this band is allocated to the FS and FSS on a co-primary basis and to MS on a secondary basis.

NGSO FSS systems can utilize this band under the FSS allocation, and in accordance with Radio Regulation S22.2 of the ITU Radio Regulations.

3.4.2 VIRGO™ System Band Plan

The VIRGO™ satellites effectively provide flexible communications paths between user terminals and gateway terminals. The user terminals are located in at least 28 full time or a larger number of time-shared (time division multiplexed) spot beams throughout each service area. The four gateway terminals are each located within individual gateway spot beams in each service area, as described in Section 3.3 above. This arrangement allows differentiation between the spectrum used for user terminals ("User Terminal Frequency Bands") and that used for gateway terminals ("Gateway Terminal Frequency Bands"), as described in Sections 3.4.2.1 and 3.4.2.2 below, respectively.

The overall frequency bands used by the VIRGO™ system are summarized in Table 3.4.2-1 below.

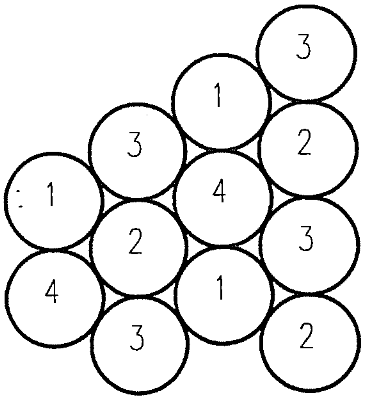
Table 3.4.2-1: VIRGO™ Frequency Band Plan

	User Terminal Frequency Bands		Gateway Terminal Frequency Bands	
	Uplink	Downlink	Uplink	Downlink
Frequency Bands	14.0-14.5 GHz	11.2-12.7 GHz	5.925-6.725 GHz 12.75-13.25 GHz 13.8-14.0 GHz 17.3-17.8 GHz	10.7-11.2 GHz 3.7-4.2 GHz
Total Bandwidth	500 MHz	1,500 MHz	2,000 MHz	1,000 MHz

3.4.2.1 User Terminal Frequency Bands

The VIRGO™ user terminal uplinks will utilize the 14.0-14.5 GHz Ku-band spectrum in both senses of circular polarization, creating an overall usable uplink spectrum of 1,000 MHz. Each user terminal uplink beam will be allocated one quarter of this (i.e., 250 MHz in a single polarization) and the overall service area will be covered with an array of potential beams operating in a 1-in-4 frequency re-use pattern, as shown in part in Figure 3.4.2.1-1. With this arrangement no two adjacent beams operate on the same frequency and polarization, and the instances where the same frequency and same polarization are used occurs only when the beams are spaced sufficiently far apart to allow full frequency/polarization re-use.

Figure 3.4.2.1-1: **Example of 1-in-4 Frequency Re-Use Pattern for User Beams**



The user terminal downlinks will operate in the 11.2-12.7 GHz Ku-band spectrum, also in both senses of circular polarization, creating an overall usable downlink spectrum of 3,000 MHz. As for the user terminal uplink, one quarter of this spectrum (i.e., 750 MHz in a single polarization) will be allocated to each user terminal downlink beam, with a similar 1-in-4 frequency re-use pattern.

The asymmetry between uplink and downlink user spectrum is deliberate. The foreseen VIRGO™ services will consist of a broad array of multi-media two-way digital applications, and the expected aggregate traffic within a user beam from users to gateways (i.e., "inbound" traffic) is expected to be approximately one third of the aggregate traffic from the gateways to users (i.e., "outbound" traffic).

3.4.2.2 Gateway Terminal Frequency Bands

Within each service area the four VIRGO™ gateway terminals will interconnect the traffic from all the user terminals operating in the 28 equivalent user beams. The aggregate bandwidth capability of the gateway beams within a service area is equal to the aggregate bandwidth capability of all the user beams within each service area, because of the bent-pipe transponder arrangement of the VIRGO™ system. To achieve this without resorting to an unacceptably large number of gateways per service area, the VIRGO™ system needs to use all available gateway spectrum.

For the VIRGO™ gateway terminal uplinks the following frequency bands will be used: 12.75-13.25 GHz (500 MHz), 13.8-14.0 GHz (200 MHz), 17.3-17.8 GHz (500 MHz) and 5.925-6.725 GHz (800 MHz). The aggregate amount of spectrum in these four distinct gateway frequency bands, after allowing for the use of both senses of circular polarization, is 4,000 MHz. Of this total gateway uplink spectrum, 250 MHz is connected to downlink throughout the entire VIRGO™ service area, which is effectively in all of the user downlink beams. Of the remaining spectrum 3,500 MHz is used to connect from each uplink gateway beam to seven separate user downlink beams. The total of 28 equivalent fully occupied user downlink beams is served by the use of the four gateway uplink beams, each serving seven user beams.

The gateway terminal downlinks will operate in the following frequency bands: 10.7-11.2 GHz (500 MHz) and 3.7-4.2 GHz (500 MHz). Accounting for the use of dual circular polarization this amounts to a total of 2,000 MHz of gateway downlink spectrum. Each gateway downlink beam is therefore capable of providing inbound links for up to eight user beams, each of which supports 250 MHz on its uplink. As for the gateway uplinks, the total of 28 equivalent user uplink beams is served by the use of the four gateway downlink beams, each serving up to eight equivalent user beams.

3.4.2.3 Channelization Plan

The VIRGO™ satellites use active phased array satellite transmit antennas (see Section 3.14) in which the power amplifiers are effectively distributed over the radiating elements of the array. There are no single high power amplifiers which are used for dedicated portions of the frequency spectrum, such as a TWTA (traveling wave tube amplifier) in a transponder of a conventional satellite. Instead, all of the distributed solid state power amplifiers operate wide-band, with each providing a small fraction of the overall RF power transmitted. As such, there is no need to channelize the frequency bands into conventional "transponder bandwidths" from the point of view of the satellite HPA constraints.

Furthermore, because of the "bent-pipe" arrangement of the payload, with connectivity provided only between gateways and user terminals (and vice versa), there is no requirement to channelize the spectrum more than is necessary to route traffic to and from the appropriate user and gateway beams. This requirement is discussed in Sections 3.4.2.1 and 3.4.2.2 above, and this is in fact the driver for the channelization plan within the VIRGO™ satellites.

Based on this, the spectrum used by the VIRGO™ system will be channelized in the satellite payload as given in Table 3.4.2-2 below.

Table 3.4.2-2: VIRGO™ System Channelization Plan

Frequency Band	Usage in VIRGO™ System	Channelization Scheme
14.0-14.5 GHz	User Terminal Uplinks	Two channels of 250 MHz bandwidth in each of two orthogonal polarizations.
11.2-12.7 GHz	User Terminal Downlinks	Two channels of 750 MHz bandwidth in each of two orthogonal polarizations. Each 750 MHz channel is subdivided into a 250 MHz sub-channel that is used for "multi-beam" downlinks and a 500 MHz sub-channel that is used for "single-beam" downlinks.
12.75-13.25 GHz	Gateway Terminal Uplinks	Two channels of 250 MHz bandwidth in each of two orthogonal polarizations.
13.8-14.0 GHz	Gateway Terminal Uplinks	One channel of 200 MHz bandwidth in each of two orthogonal polarizations. (See Note 1)
17.3-17.8 GHz	Gateway Terminal Uplinks	Two channels of 250 MHz bandwidth in each of two orthogonal polarizations.
5.925-6.725 GHz	Gateway Terminal Uplinks	Three channels of 250 MHz bandwidth plus one channel of 50 MHz bandwidth in each of two orthogonal polarizations. (see Note 1)
10.7-11.2 GHz	Gateway Terminal Downlinks	Two channels of 250 MHz bandwidth in each of two orthogonal polarizations.
3.7-4.2 GHz	Gateway Terminal Downlinks	Two channels of 250 MHz bandwidth in each of two orthogonal polarizations.

Note 1: The gateway uplink channels of 200 MHz and 50 MHz are combined in the satellite payload to form one user downlink channel of 250 MHz

3.4.2.4 Order Wire Control Channels

Some of the communications capacity between the gateways and the user terminals will be set aside for order wire control channels. Current estimates suggest that an allocation of five megabits per second per user beam in both the outbound and inbound directions is appropriate, but further system development may result in changes to these allocations.

The outbound order wire control channel will consist of a TDM (Time Division Multiplex) signal containing control data destined for all the user terminals within a user beam, with individual headers preceding each control message to identify the individual user terminal to which the control message applies.

The inbound order wire control channel will use an FDMA (Frequency Division Multiple Access) scheme with each user terminal transmitting short data messages, when necessary, each modulated on its own RF carrier. The access protocol in this control channel will be a derivative of the ALOHA technique currently used by the inbound links of many VSAT networks.

The order wire channel will be used to carry network management information only, including the following:

- Requests by user terminals for satellite capacity. These requests will indicate the quantity and type of capacity required;
- Response by the RNCC/gateway to user terminal requests for capacity, indicating the availability of such capacity, and the frequency assigned for the transmission;
- Control information from the gateway to the user terminal for the implementation of uplink power control;
- Transmissions from the user terminals to the RNCC/gateway reporting on the health status of the user terminal equipment;
- Commands from the RNCC/gateway to the individual user terminals in the event that it is necessary to cease a particular uplink transmission;
- Transmission from the SOCC/RNCC/gateway of the latest VIRGO™ constellation ephemeris data.

The order wire control channels will operate with transmit power spectral densities that do not exceed those of the communications traffic channels, and as such do not cause any additional interference. These order wire control links are made more robust by the use of a higher level of FEC coding (1/3 rate FEC) than is used on the communications traffic channels, as the reduction in spectral efficiency for these relatively narrowband channels is not a problem. The exact frequencies to be used for these order wire control channels have not yet been determined, and will be decided only as a result of the more detailed studies that are underway. From an interference point of view, these order wire control channels are the same as the communications traffic channels so there is no need to distinguish them for the purpose of this application.

3.4.2.5 Beacons

On-board generated downlink beacons are used to ensure optimum tracking of the active VIRGO™ satellites by the user and gateway earth stations, and for uplink power control. The beacons consist of narrow-band (1 kHz occupied bandwidth) carriers modulated with pseudo-random noise bit sequences for signal spreading purposes.

The beacons must be located within the user terminal downlink spectrum in order to minimize the cost of the beacon receiver functions in the user terminals. Gateways will also use these same downlink beacons through the use of special beacon receivers even though the beacons operate within the user terminal downlink frequency band. Four such beacons are provided with opposite circular polarizations and in different halves of the user downlink frequency band in order to minimize cost impact to user terminals. These beacons are currently planned to be implemented at the extreme ends of the user terminal downlink frequency band as follows:

Beacons 1 & 2:	Center frequency 11.2001 GHz in LHC and RHC polarizations
Beacons 3 & 4:	Center frequency 12.6999 GHz in LHC and RHC polarizations

All VIRGO™ satellites will operate with beacons transmitting at the same frequencies as those given above. The angular spacing between the sequential VIRGO™ satellites in the same orbit plane will be used to distinguish between the "rising" and "setting" satellites.

The exact frequencies of these beacons may be changed as a result of coordination with other users of the spectrum. Further details of these beacons are given in Sections 3.6.3 and 3.8.8 below.

3.4.2.6 TT&C Links

Telemetry, Tracking and Command ("TT&C") functions will be performed at C-band for the launch and early operations phase ("LEOP"), normal on-station mode, and emergency mode, using frequency assignments (± 1 MHz) at the edges of the conventional C-band frequency ranges. The preferred assignments are as follows:

Telecommand and Ranging Uplinks:	5.926 GHz and 6.424 GHz
Telemetry and Ranging Downlinks:	3.701 GHz and 4.199 GHz

The final frequency assignments for these TT&C transmissions will be determined only after coordination with all affected users of this band. As an aid to coordination with existing C-band satellites, the possibility is being investigated of prohibiting the normal-mode VIRGO™ TT&C transmissions when potential interference could occur with respect to GSO satellites, including GSO satellites with inclinations up to 5°.

3.4.2.7 Inter-Satellite Links

Line of sight connectivity can be achieved between the VIRGO™ satellites during the active arc of their orbits. This feature of the constellation can be exploited to allow inter-regional communications to be established without the need to "double-hop" through gateway earth stations. The IF switch in the VIRGO™ satellite payload will permit certain sub-channels to and from each user and gateway beam to be routed via the ISL to the active satellites in the other service areas.

VIRGO™ will employ optical ISLs to support this requirement, eliminating coordination concerns with other systems using RF-based ISLs.

3.5 SYSTEM CAPACITY

The VIRGO™ system provides simultaneous service in nine regional service areas around the world. Within each of the regional service areas the system provides a total outbound (gateway-to-user) transmission bandwidth of 14.25 GHz and a total inbound (user-to-gateway) transmission bandwidth of 7 GHz. Using the proposed concatenated forward error correction ("FEC") coding schemes (½ rate inner convolutional code together with outer Reed-Solomon code), and taking account of the necessary guard bands between carriers, this bandwidth will support an aggregate bit-rate of between 10 and 12 GigaBits/s outbound and between 5 and 6 GigaBits/s inbound per service area, depending on the particular traffic types.

All the inbound traffic is from individual user beams to gateways. Of the outbound traffic, 200 MegaBits/s is used in "multi-beam" mode from a single gateway to all downlink beams of the service area (effectively configured as one large downlink beam). The remaining 9.5 to 11 GigaBits/s is connected between gateways and individual downlink spot beams.

The high system capacity is achieved by correspondingly high levels of frequency reuse, which can be summarized as follows:

- Fourteen times re-use in the user terminal uplink frequency band

- Fourteen times reuse in two-thirds of the user terminal downlink frequency band.

  Two times reuse in the remaining one-third which is used in multi-beam mode.
- Eight times reuse in both uplink and downlink gateway frequency bands.

3.6 SATELLITE TRANSMIT CAPABILITY

3.6.1 User Terminal Beams

The satellite transmit performance has been designed to provide high quality service into user terminals with antennas of equivalent apertures as small as 45 cm in diameter. Details of these user terminals is given in Section 3.16.1 below.

Due to the use of elliptical orbits, the altitude of the VIRGO™ satellite, during its active part of the orbit, varies from around 17,500 km to around 27,300 km, corresponding to a change in path loss of 3.9 dB. The transmit earth stations compensate for this change of path loss by adjusting the level of the uplink carriers so that they drive the satellites optimally during all parts of the active orbit arc. This feature is part of the uplink power control scheme which is discussed in detail in Section 3.16.1 below.

The VIRGO™ satellites use active phased array antennas. As a result, the conventional concept of separate satellite high power amplifiers ("HPAs") connected to a downlink antenna with a fixed gain is not appropriate. Instead, the satellite transmit capability can be thought of as a pooled power resource whose magnitude can be related to the aggregate power of the transmit amplifiers that make up the active antenna (see Section 3.14 for satellite capability in this respect). Similarly the gain of the satellite transmit antenna is non-constant, as the beams are reconfigured in real-time to provide optimal continuity of service to the users. This involves the constant and automatic adjustment of the individual spot beams as the satellite passes through the active part of its orbit, so as to achieve near constant beam shapes on the surface of the Earth at all times.

The use of an active phased array antenna on the satellites also causes another departure from the conventional in terms of the "transponder" bandwidths. There are in fact no such "transponders" on the VIRGO™ satellites; instead the available satellite transmit capability can be used anywhere across the overall-user downlink frequency band. The satellite power, bandwidth and beam resources are in fact managed by the gateway terminals (augmented by the TT&C station for changes in the on-board channelization and connectivity) by means of setting the amplitude and frequency of the gateway uplink carriers.

With all the above considerations in mind, the maximum satellite transmit performance can best be defined in terms of the PFD (spectral density) produced at the surface of the Earth at the peak of the downlink beams and at any part of the active service arc. The performance of the VIRGO™ user downlink beams in this respect is as follows:

<u>11.2-12.7 GHz:</u>

Maximum PFD at the Earth's surface will not exceed -151.0 dBW/m^2/4kHz.

3.6.2 Gateway Terminal Beams

The VIRGO™ satellite gateway terminal beams are similarly generated by active phased array antennas at both Ku and C-bands. These beams are constructed to have the same gain and pattern as the user link antenna beams described earlier, and like them, are steering actively. The satellite transmit performance in the gateway frequency bands is therefore defined as follows:

<u>10.7-11.2 GHz:</u>

Maximum PFD at the Earth's surface will not exceed -160.0 dBW/m^2/4kHz.

3.7-4.2 GHz:

Maximum PFD at the Earth's surface will not exceed -165.0 dBW/m^2/4kHz.

3.6.3 Beacon Signals

The beacon signals, which operate in the user terminal downlink bands of 11.2-12.7 GHz, will operate at 6 dB higher PFD spectral density (per-Hz) than the communications signals in order to provide greater link robustness. However, as the bandwidth of these beacon signals is only 1 kHz, the worst case PFD, when averaged over 4 kHz, is the same as that of the user downlink communications signals in this band, and are therefore as follows:

- Maximum PFD at the Earth's surface will not exceed -151.0 dBW/m^2/4kHz.

Further details of the beacon signals are given in Sections 3.4.2.5 and 3.8.8.

3.7 SATELLITE RECEIVE CAPABILITY

3.7.1 User Terminal Beams

3.7.1.1 Gain-to-Noise Temperature Ratio (G/T) for User Terminal Beams

The G/T performance of the user terminal receive beams is as follows:

12.75-13.25 & 13.8-14.0 GHz:

Maximum (beam-peak):	+10.2 dB/K
Beam edge:	+7.2 dB/K

3.7.1.2 Satellite Channel Gain for User-to-Gateway Links

In a conventional system, the satellite channel gain is defined in terms of the Saturation Flux Density ("SFD"). The SFD is the power flux density at the input to the satellite receive antenna that just produces saturation of the satellite HPA. However, the concept of SFD is not relevant to the linear broad-band communications channels of the VIRGO™ satellites. Instead the linear gain from output of the satellite receive antenna to the input of the satellite transmit antenna is more appropriate and is used in link budget design for this type of system. This performance parameter can be varied in the range 110 dB to 135 dB for the overall user to gateway communications channels.

3.7.2 Gateway Terminal Beams

3.7.2.1 Gain-to-Noise Temperature Ratio (G/T) for Gateway Terminal Beams

The G/T performance of the gateway terminal receive beams is as follows:

- 12.75-13.25 & 13.8-14.0 GHz:

  Maximum (beam-peak): +10.2 dB/K

  Beam edge: +7.2 dB/K

- 17.3-17.8 GHz:

  Maximum (beam peak): +9.0 dB/K

  Beam edge: +6.0 dB/K

- 5.925-6.725 GHz:

  Maximum (beam peak): +5.2 dB/K

  Beam edge: +2.2 dB/K

3.7.2.2 Satellite Channel Gain for Gateway-to-User Links

The linear gain from output of the satellite receive antenna to the input of the satellite transmit antenna for the overall gateway to user communications channels can be varied in the range 110 dB to 135 dB.

3.8 TRANSMISSION CHARACTERISTICS

All communications traffic transmissions in the VIRGO™ system will be digital and will use Quadrature Phase Shift Keying ("QPSK") modulation. Channel coding will be used to increase the baseband performance of the communications channels.

All communications traffic transmissions in the VIRGO™ System will use FDMA/FDM, supplemented in some cases by TDMA. The bandwidth of the individual carriers will vary depending on the transmission data rate of each link. No signal spreading will be used, other than that resulting from the FEC coding employed.

3.8.1 Communications Transmissions Between Gateway and User Terminals

All communications transmissions between gateways and users will use concatenated forward error correction ("FEC") coding schemes (½ rate inner convolutional code together with an outer Reed-Solomon code)

3.8.2 Order Wire Links

The order wire links will use 1/3 rate FEC convolutional coding.

3.8.3 TT&C Links

VIRGO™ TT&C links will employ ½ rate convolutional forward error correction encoding with cyclic redundancy checks. together with acknowledgment of all commands and all data receipt. All TT&C links will be encrypted.

3.8.4 Emission Designators

All communications traffic emissions in the VIRGO™ system will be digital signals using phase shift keyed modulation. Due to the use of transparent wide-band satellite channels there are few inherent limitations on the range of carrier data rates that can be used, but typically it is expected that the a range from 64 kBits/s to 155 MBits/s will be used.

Based on this expected range of traffic types the following emission designators are provided, and these can be assumed to be required in all frequency bands proposed to be used by the VIRGO™ system. Note that the emission designators include the occupied bandwidth which is between 1.15 and 1.4 times the data rate, depending on the channel filtering used:

90K0G7W
170KG7W
350KG7W
500KG7W
960KG7W
1M85G7W
2M45G7W
4M80G7W
9M60G7W
19M2G7W
36M0G7W
52M0G7W
180MG7W

In addition, the following emission designators are applicable to the beacon and TT&C transmissions in the VIRGO™ system:

Beacon:	1K00GXN
Telecommand:	45K0G1D
Telemetry:	45K0G1D

3.8.5 Transmission Channel Frequency Response and Unwanted Emissions

The channelization scheme described in Section 3.4.2.3 describes satellite transmitted bandwidths of 250 MHz, 500 MHz and 750 MHz. The corresponding unwanted emission masks (out-of-band responses) for each of these channel bandwidths are given in Figures 3.8.5-1, 3.8.5-2 and 3.8.5-3 respectively.

The in-band frequency responses of these channels will be consistent with normal satellite and earth station equipment performance standards and sufficient to ensure that negligible distortion occurs to the range of digital transmissions to be used. The exact specifications for these in-band frequency responses have not yet been fully defined and will be provided to the Commission in due course if required.

Figure 3.8.5-1: Unwanted Emission Mask for 250 MHz Channels

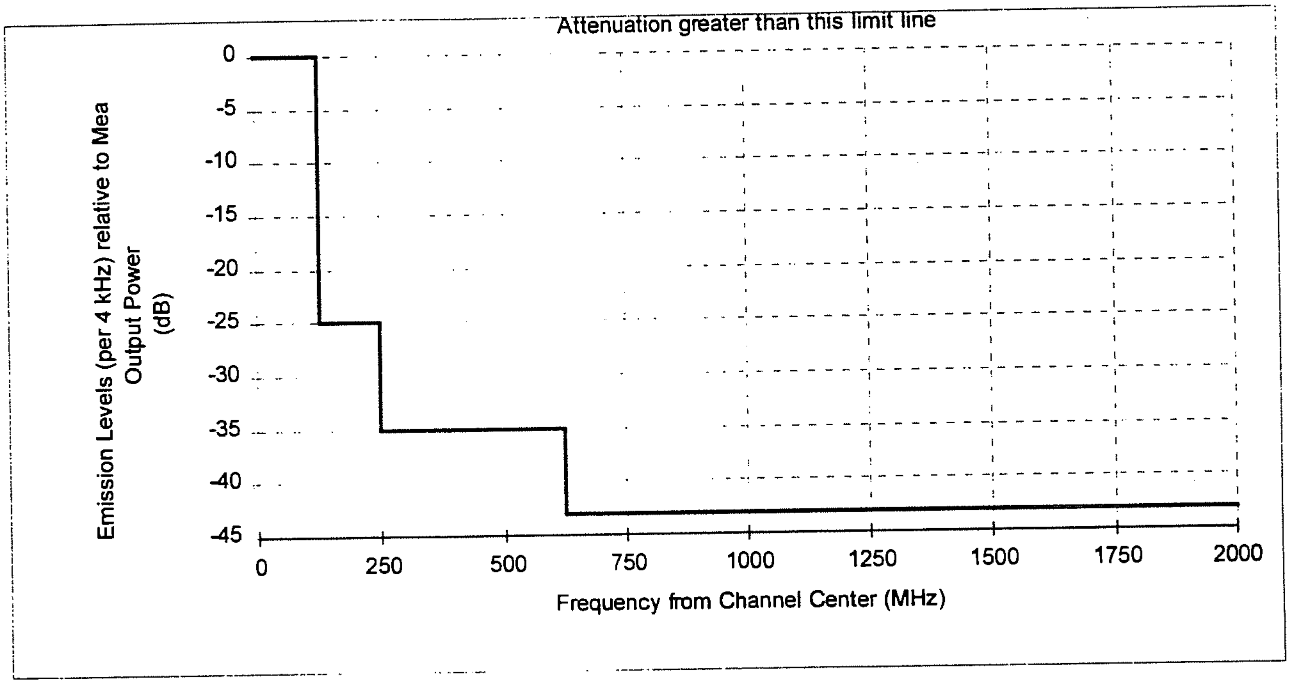


Figure 3.8.5-2: Unwanted Emission Mask for 500 MHz Channels

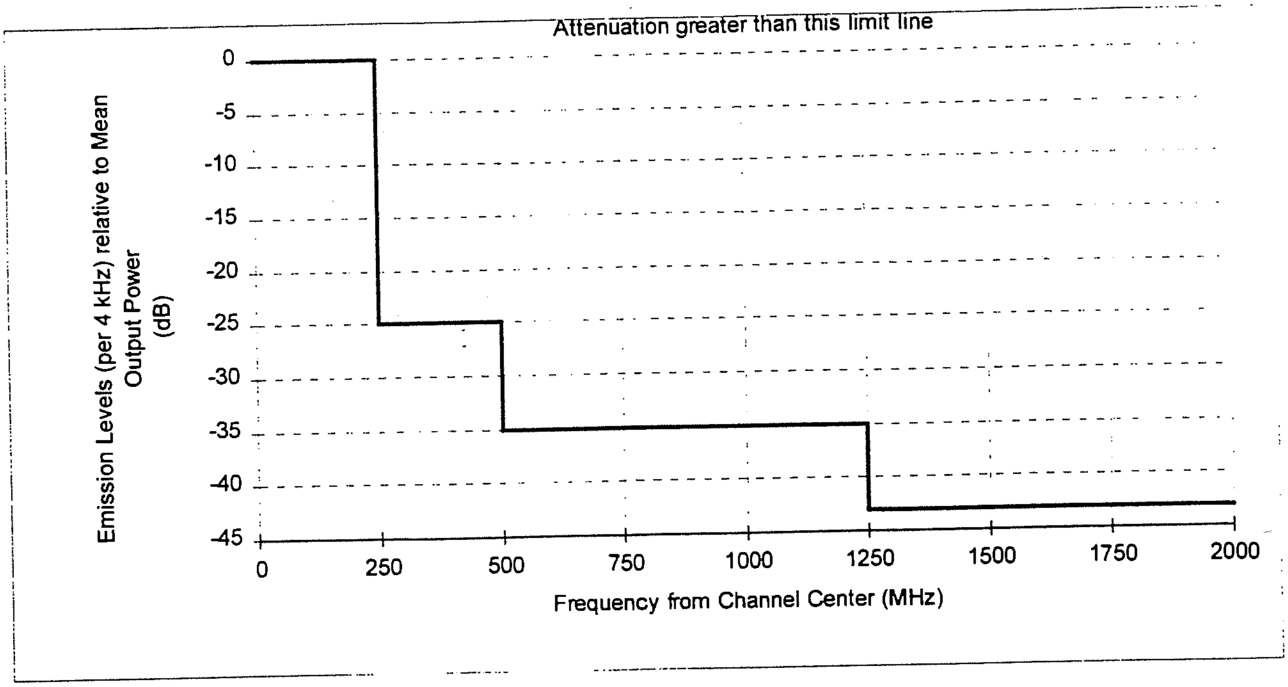
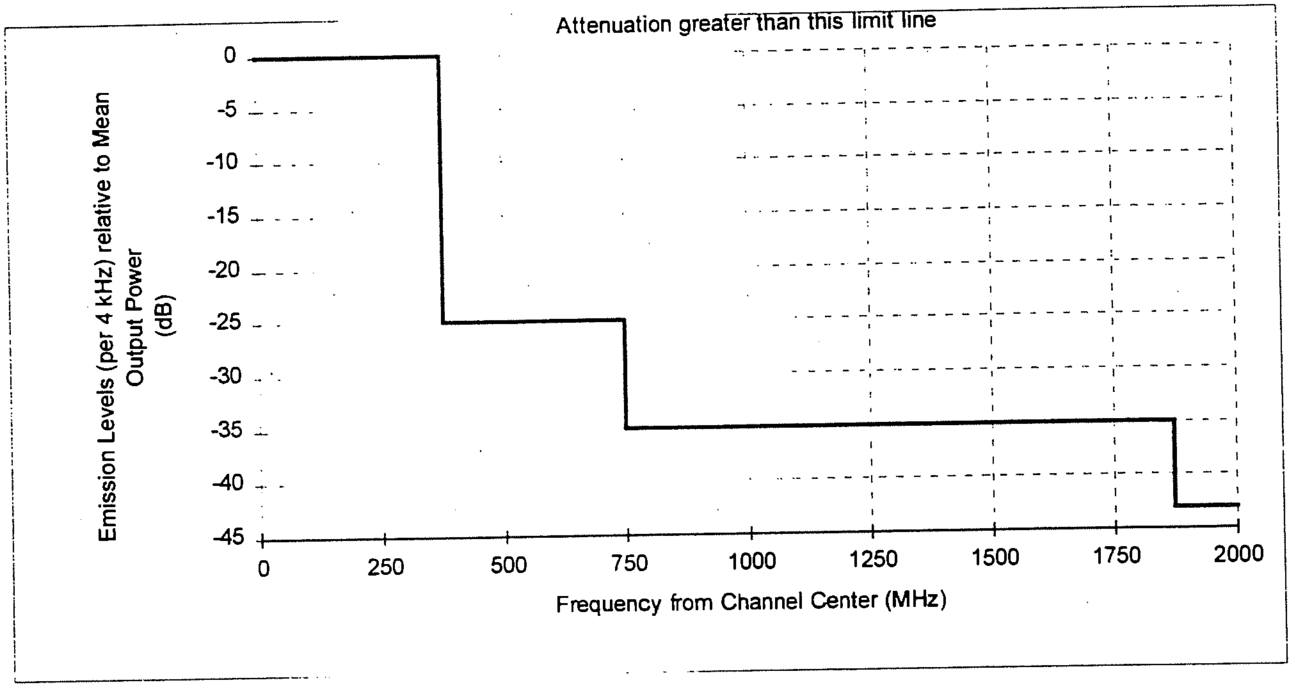


Figure 3.8.5-3: Unwanted Emission Mask for 750 MHz Channels



3.8.6 Frequency Tolerance

The local oscillator frequency stability in the VIRGO™ satellite communications payload will determine the accuracy of the frequency conversion between uplink and downlink transmissions. This frequency conversion error shall not exceed ±5 in 10^6 under all circumstances.

3.8.7 Cessation of Emissions

All carriers in the VIRGO™ satellite system, both those transmitted from gateway terminals as well as those from user terminals, will be able to be individually turned on and off through the network management functions controlled by the RNCC.

3.8.8 Downlink Beacon Applications

3.8.8.1 Earth Station Tracking

All user and gateway terminals must track the transmitting and receiving VIRGO™ satellite as it moves through the active part of its orbit. This is achieved by a combination of computer prediction (based on ephemeris data supplied on a regular basis by the RNCC/Gateway to all terminals via the order wire links) and tracking by the terminals of the downlink beacon transmitted by the VIRGO™ satellites. The EIRP spectral density (per-Hz) of the downlink beacons is approximately 6 dB higher than communications downlinks in order to provide more robust links for this important function. Further details of the frequencies, power levels and emission characteristics of these beacons are given in Sections 3.4.2.5, 3.6.3 and 3.8.4 respectively.

3.8.8.2 Uplink Power Control

Correct setting of the uplink carrier power levels of both the user and gateway terminals is essential to the correct operation of the VIRGO™ system. This issue is discussed in more detail in Sections 3.16.1 and 3.16.2 below. Measurement by the gateway terminals of the fading on the beacon downlink signal is essential to allow the gateway to distinguish between uplink and downlink fades on the inbound links, and hence to the proper implementation of uplink power control for the user terminals. It is also used to determine fading on the satellite-gateway path and hence derive uplink power control information for the gateway terminal transmissions.

3.9 LINK BUDGETS

All communications links in the VIRGO™ system will be digital, with the same modulation type and FEC coding. As such, the link budgets for various data rates are very similar in that they assume that the digital spectra are essentially flat. Other minor differences between the actual link budgets for different data rates are a result of slightly different channel filtering and the performance of the demodulators. There are, however, significant differences in the link budgets between the outbound (i.e., gateway-to-user) and inbound (i.e., user-to-gateway) links. Therefore, in this section there are just two types of link budget provided for each major frequency band, and these are intended to demonstrate the performance of the system for a wide range of actual data rates. The spectral densities of the signals provided in these links represents the maximum transmit powers regardless of actual link data rate.

Table 3.9-1 gives the outbound link between a 5 meter transmitting gateway terminal operating in the 12.75-13.25 GHz and 13.8-14.0 GHz bands and a minimum sized 45 cm receiving user terminal operating in the 11.2-12.7 GHz band. The actual data rate of this link is 36 MBits/s. In practice the link power levels will be constantly changing by means of uplink power control as the satellite moves through its active orbit arc, but this link budget shows the near worst case situation when the satellite is at the maximum distance from anywhere in the service area. Three cases are shown in the columns of the link budget: the first is the clear sky case; the second includes a rain fade on the uplink which is compensated by uplink power control; the third includes a rain fade on the downlink which results in zero residual margin. Table 3.9-2 gives a similar outbound link budget but for the upper Ku-band gateway uplink frequency range (17.3-17.8 GHz). Table 3.9-3 gives the third type of outbound link budget for the gateway uplink operating in C-band (5.925-6.725 GHz).

Tables 3.9-4 and 3.9-5 give the two cases of inbound link budgets between the transmitting 45 cm user terminal and the 5 meter receiving gateway terminal, for gateway downlinks in the Ku-band (10.7-11.2 GHz) and C-band (3.7-4.2 GHz) respectively. The link data rate in this example is 2 MBits/s. Similar cases of clear sky, uplink rain fade and downlink rain fade are shown, as for the outbound links.

The link budgets shown in this section are compatible with 99.9% availability on the user links (both uplink and downlink) in all the rain regions of CONUS with the exception of the small area in the south-east which is rain region N. In this region the availability is 99.7% with the same size user terminal, or higher with a corresponding increase in user terminal size. The gateway links are all 99.99% availability for the C-band and lower Ku-band (< 14 GHz) links, provided that the gateways are not located in rain region N. In the upper Ku-band (> 17 GHz) gateway links the availability in rain region M drops to 99.97%, unless the gateway antenna size is increased.

Table 3.9-1: Outbound Link Budget (14 GHz uplink)

VIRGO Link Budget

01.Jan.99

Gateway-to-User (14/12 GHz)

Earth stations: Tx (5m) to Rx (0.45m)

36000Kbps / 1/2 FEC / QPSK Modulation / Alpha = 25

Link Parameters		**Clear Sky**	**Uplink Fade**	**Downlink Fade**
Link Geometry:				
Tx ES Range to Satellite (max)	(km)	31150	31150	31150
Rx ES Range to Satellite (max)	(km)	31150	31150	31150
Uplink (per carrier):				
Carrier Frequency	(MHz)	14000	14000	14000
Tx ES Antenna Diameter	(m)	5.0	5.0	5.0
Tx ES Power to Antenna	(W)	6.4	143.3	6.4
Tx ES PSD to Antenna - per 4 kHz	(dBW/4kHz)	-32.4	-18.9	-32.4
Tx ES Antenna Gain (60% eff.)	(dB)	55.1	55.1	55.1
Tx ES EIRP per Carrier	(dBW)	63.1	76.6	63.1
Atmospheric and Other Losses	(dB)	0.5	14.0	0.5
Free Space Loss	(dB)	205.2	205.2	205.2
Satellite:				
Total PFD at Satellite	(dBW/m2)	-98.2	-98.2	-98.2
Satellite Rx Gain towards Tx ES (beam edge)	(dBi)	35.0	35.0	35.0
Received Signal Power	(dBW)	-107.6	-107.6	-107.6
Satellite Receive System Noise Temperature	(K)	600	600	600
Satellite G/T towards Tx ES (beam edge)	(dB/K)	7.2	7.2	7.2
Satellite Channel Gain	(dB)	120.0	120.0	120.0
Satellite Tx Power	(Watts)	17	17	17
Satellite Tx Gain towards Rx ES (beam edge)	(dBi)	35.0	35.0	35.0
Satellite Tx EIRP towards Rx ES (beam edge)	(dBW)	47.4	47.4	47.4
Downlink (per carrier):				
Carrier Frequency	(MHz)	11950	11950	11950
Atmospheric and Other Losses	(dB)	0.5	0.5	4.0
Free Space Loss	(dB)	203.9	203.9	203.9
PFD at Earth's Surface (in 4 kHz)	(dBW/m^2/4kHz)	-151.5	-151.5	-155.0
Rx ES Antenna Diameter	(m)	0.45	0.45	0.45
Rx ES Antenna Gain (60% eff.)	(dB)	32.8	32.8	32.8
Rx ES G/T	(dB/K)	12.4	12.4	11.8
System (LNA+Sky) Noise Temp.	(K)	110	110	125
Total Link:				
Information Bit Rate (w/o coding)	(kbps)	36,000	36,000	36,000
FEC Rate	(fraction)	1/2	1/2	1/2
Modulation Type	(? PSK)	QPSK	QPSK	QPSK
Rx filter "alpha" factor	(%)	25.0	25.0	25.0
Carrier Noise Bandwidth	(kHz)	45,000	45,000	45,000
(C/N) - Thermal Uplink	(dB)	16.7	16.7	16.7
(C/N) - Thermal Downlink	(dB)	7.5	7.5	3.4
(C/I) - Intermodulation Noise	(dB)	22.0	22.0	22.0
(C/I) - Cross-Polar Interference	(dB)	25.0	25.0	25.0
(C/I) - Multi-Beam Effects	(dB)	18.0	18.0	18.0
(C/N+I) - Total Actual	(dB)	6.5	6.5	3.0
(Eb/No) - Total Actual	(dB)	7.5	7.5	4.0
(Eb/No) - Total Required	(dB)	4.0	4.0	4.0
Excess Margin	(dB)	3.5	3.5	0.0

Table 3.9-2: Outbound Link Budget (17.3-17.8 GHz uplink)

VIRGO Link Budget

01.Jan.99

Gateway-to-User (17/12 GHz)

Earth stations: Tx (5m) to Rx (0.45m)

36000Kbps / 1/2 FEC / QPSK Modulation / Alpha = 25

Link Parameters		Clear Sky	Uplink Fade	Downlink Fade
Link Geometry:				
Tx E/S Range to Satellite (max)	(km)	31,150	31,150	31,150
Rx E/S Range to Satellite (max)	(km)	31,150	31,150	31,150
Uplink (per carrier):				
Carrier Frequency	(MHz)	17,550	17,550	17,550
Tx E/S Antenna Diameter	(m)	5.0	5.0	5.0
Tx E/S Power to Antenna	(W)	6.5	183.2	6.5
Tx E/S PSD to Antenna - per 4 kHz	(dBW/4kHz)	-32.4	-17.9	-32.4
Tx E/S Antenna Gain (60% eff.)	(dB)	57.0	57.0	57.0
Tx E/S EIRP per Carrier	(dBW)	65.2	79.7	65.2
Atmospheric and Other Losses	(dB)	0.5	15.0	0.5
Free Space Loss	(dB)	207.2	207.2	207.2
Satellite:				
Total PFD at Satellite	(dBW/m2)	-96.2	-96.2	-96.2
Satellite Rx Gain towards Tx E/S (beam edge)	(dBi)	35.0	35.0	35.0
Received Signal Power	(dBW)	-107.5	-107.5	-107.5
Satellite Receive System Noise Temperature	(K)	800	800	800
Satellite G/T towards Tx E/S (beam edge)	(dB/K)	6.0	6.0	6.0
Satellite Channel Gain	(dB)	120.0	120.0	120.0
Satellite Tx Power	(Watts)	18	18	18
Satellite Tx Gain towards Rx E/S (beam edge)	(dBi)	35.0	35.0	35.0
Satellite Tx EIRP towards Rx E/S (beam edge)	(dBW)	47.5	47.5	47.5
Downlink (per carrier):				
Carrier Frequency	(MHz)	11950	11950	11950
Atmospheric and Other Losses	(dB)	0.5	0.5	4.0
Free Space Loss	(dB)	203.9	203.9	203.9
PFD at Earth's Surface (in 4 kHz)	(dBW/m^2/4kHz)	-151.4	-151.4	-154.9
Rx E/S Antenna Diameter	(m)	0.45	0.45	0.45
Rx E/S Antenna Gain (60% eff.)	(dB)	32.8	32.8	32.8
Rx E/S G/T	(dB/K)	12.4	12.4	11.8
System (LNA+Sky) Noise Temp.	(K)	110	110	125
Total Link:				
Information Bit Rate (w/o coding)	(kbps)	36,000	36,000	36,000
FEC Rate	(fraction)	1/2	1/2	1/2
Modulation Type	(? PSK)	QPSK	QPSK	QPSK
Rx filter "alpha" factor	(%)	25.0	25.0	25.0
Carrier Noise Bandwidth	(kHz)	45,000	45,000	45,000
(C/N) - Thermal Uplink	(dB)	15.5	15.5	15.5
(C/N) - Thermal Downlink	(dB)	7.6	7.6	3.5
(C/I) - Intermodulation Noise	(dB)	22.0	22.0	22.0
(C/I) - Cross-Polar Interference	(dB)	25.0	25.0	25.0
(C/I) - Multi-Beam Effects	(dB)	18.0	18.0	18.0
(C/N+I) - Total Actual	(dB)	6.4	6.4	3.0
(Eb/No) - Total Actual	(dB)	7.4	7.4	4.0
(Eb/No) - Total Required	(dB)	4.0	4.0	4.0
Excess Margin	(dB)	3.4	3.4	0.0

Table 3.9-3: Outbound Link Budget (5.925-6.725 GHz uplink)

VIRGO Link Budget

01.Jan.99

Gateway-to-User (6/12 GHz)

Earth stations: Tx (5m) to Rx (0.45m)

36000Kbps / 1/2 FEC / QPSK Modulation / Alpha = 25

Link Parameters		Clear Sky	Uplink Fade	Downlink Fade
Link Geometry:				
Tx E/S Range to Satellite (max)	(km)	31,150	31,150	31,150
Rx E/S Range to Satellite (max)	(km)	31,150	31,150	31,150
Uplink (per carrier):				
Carrier Frequency	(MHz)	6,325	6,325	6,325
Tx E/S Antenna Diameter	(m)	5.0	5.0	5.0
Tx E/S Power to Antenna	(W)	19.5	72.4	19.5
Tx E/S PSD to Antenna - per 4 kHz	(dBW/4kHz)	-27.6	-21.9	-27.6
Tx E/S Antenna Gain (60% eff.)	(dB)	48.2	48.2	48.2
Tx E/S EIRP per Carrier	(dBW)	61.1	66.8	61.1
Atmospheric and Other Losses	(dB)	0.3	6.0	0.3
Free Space Loss	(dB)	198.3	198.3	198.3
Satellite:				
Total PFD at Satellite	(dBW/m2)	-100.1	-100.1	-100.1
Satellite Rx Gain towards Tx E/S (beam edge)	(dBi)	30.0	30.0	30.0
Received Signal Power	(dBW)	-107.5	-107.5	-107.5
Satellite Receive System Noise Temperature	(K)	600	600	600
Satellite G/T towards Tx E/S (beam edge)	(dB/K)	2.2	2.2	2.2
Satellite Channel Gain	(dB)	120.0	120.0	120.0
Satellite Tx Power	(Watts)	18	18	18
Satellite Tx Gain towards Rx E/S (beam edge)	(dBi)	35.0	35.0	35.0
Satellite Tx EIRP towards Rx E/S (beam edge)	(dBW)	47.5	47.5	47.5
Downlink (per carrier):				
Carrier Frequency	(MHz)	11950	11950	11950
Atmospheric and Other Losses	(dB)	0.5	0.5	4.0
Free Space Loss	(dB)	203.9	203.9	203.9
PFD at Earth's Surface (in 4 kHz)	(dBW/m^2/4kHz)	-151.4	-151.4	-154.9
Rx E/S Antenna Diameter	(m)	0.45	0.45	0.45
Rx E/S Antenna Gain (60% eff.)	(dB)	32.8	32.8	32.8
Rx E/S G/T	(dB/K)	12.4	12.4	11.8
System (LNA+Sky) Noise Temp.	(K)	110	110	125
Total Link:				
Information Bit Rate (w/o coding)	(kbps)	36,000	36,000	36,000
FEC Rate	(fraction)	1/2	1/2	1/2
Modulation Type	(? PSK)	QPSK	QPSK	QPSK
Rx filter "alpha" factor	(%)	25.0	25.0	25.0
Carrier Noise Bandwidth	(kHz)	45,000	45,000	45,000
(C/N) - Thermal Uplink	(dB)	16.7	16.7	16.7
(C/N) - Thermal Downlink	(dB)	7.5	7.5	3.5
(C/I) - Intermodulation Noise	(dB)	22.0	22.0	22.0
(C/I) - Cross-Polar Interference	(dB)	25.0	25.0	25.0
(C/I) - Multi-Beam Effects	(dB)	18.0	18.0	18.0
(C/N+I) - Total Actual	(dB)	6.5	6.5	3.1
(Eb/No) - Total Actual	(dB)	7.5	7.5	4.0
(Eb/No) - Total Required	(dB)	4.0	4.0	4.0
Excess Margin	(dB)	3.5	3.5	0.0

Table 3.9-4: Inbound Link Budget (10.7-11.2 GHz downlink)

VIRGO Link Budget

01.Jan.99

User-to-Gateway (14/11 GHz)

Earth stations: Tx (0.45m) to Rx (5m)

2000Kbps / 1/2 FEC / QPSK Modulation / Alpha = 25

Link Parameters		Clear Sky	Uplink Fade	Downlink Fade
Link Geometry:				
Tx E/S Range to Satellite (max)	(km)	31,150	31,150	31,150
Rx E/S Range to Satellite (max)	(km)	31,150	31,150	31,150
Uplink (per carrier):				
Carrier Frequency	(MHz)	14,250	14,250	14,250
Tx E/S Antenna Diameter	(m)	0.45	0.45	0.45
Tx E/S Power to Antenna	(W)	2.7	9.4	2.7
Tx E/S PSD to Antenna - per 4 kHz	(dBW/4kHz)	-23.7	-18.2	-23.7
Tx E/S Antenna Gain (60% eff.)	(dB)	34.3	34.3	34.3
Tx E/S EIRP per Carrier	(dBW)	38.6	44.1	38.6
Atmospheric and Other Losses	(dB)	0.5	6.0	0.5
Free Space Loss	(dB)	205.4	205.4	205.4
Satellite:				
Total PFD at Satellite	(dBW/m2)	-122.8	-122.8	-122.8
Satellite Rx Gain towards Tx E/S (beam edge)	(dBi)	35.0	35.0	35.0
Received Signal Power	(dBW)	-132.3	-132.3	-132.3
Satellite Receive System Noise Temperature	(K)	600	600	600
Satellite G/T towards Tx E/S (beam edge)	(dB/K)	7.2	7.2	7.2
Satellite Channel Gain	(dB)	120.0	120.0	120.0
Satellite Tx Power	(Watts)	0.058	0.058	0.058
Satellite Tx Gain towards Rx E/S (beam edge)	(dBi)	35.0	35.0	35.0
Satellite Tx EIRP towards Rx E/S (beam edge)	(dBW)	22.7	22.7	22.7
Downlink (per carrier):				
Carrier Frequency	(MHz)	11,950	11,950	11,950
Atmospheric and Other Losses	(dB)	0.5	0.5	7.0
Free Space Loss	(dB)	203.9	203.9	203.9
PFD at Earth's Surface (in 4 kHz)	(dBW/m^2/4kHz)	-163.7	-163.7	-170.2
Rx E/S Antenna Diameter	(m)	5.00	5.00	5.00
Rx E/S Antenna Gain (60% eff.)	(dB)	53.7	53.7	53.7
Rx E/S G/T	(dB/K)	33.3	33.3	32.7
System (LNA+Sky) Noise Temp.	(K)	110	110	125
Total Link:				
Information Bit Rate (w/o coding)	(kbps)	2,000	2,000	2,000
FEC Rate	(fraction)	1/2	1/2	1/2
Modulation Type	(? PSK)	QPSK	QPSK	QPSK
Rx filter "alpha" factor	(%)	25.0	25.0	25.0
Carrier Noise Bandwidth	(kHz)	2,500	2,500	2,500
(C/N) - Thermal Uplink	(dB)	4.5	4.5	4.5
(C/N) - Thermal Downlink	(dB)	16.2	16.2	9.2
(C/I) - Intermodulation Noise	(dB)	22.0	22.0	22.0
(C/I) - Cross-Polar Interference	(dB)	25.0	25.0	25.0
(C/I) - Multi-Beam Effects	(dB)	18.0	18.0	18.0
(C/N+I) - Total Actual	(dB)	3.9	3.9	3.0
(Eb/No) - Total Actual	(dB)	4.9	4.9	4.0
(Eb/No) - Total Required	(dB)	4.0	4.0	4.0
Excess Margin	(dB)	0.9	0.9	0.0

Table 3.9-5: Inbound Link Budget (3.7-4.2 GHz downlink)

VIRGO Link Budget

01.Jan.99

User-to-Gateway (14/4 GHz)

Earth stations: Tx (0.45m) to Rx (5m)

2000Kbps / 1/2 FEC / QPSK Modulation / Alpha = 25

Link Parameters		Clear Sky	Uplink Fade	Downlink Fade
Link Geometry:				
Tx E/S Range to Satellite (max)	(km)	31,150	31,150	31,150
Rx E/S Range to Satellite (max)	(km)	31,150	31,150	31,150
Uplink (per carrier):				
Carrier Frequency	(MHz)	14,250	14,250	14,250
Tx E/S Antenna Diameter	(m)	0.45	0.45	0.45
Tx E/S Power to Antenna	(W)	2.7	9.6	2.7
Tx E/S PSD to Antenna - per 4 kHz	(dBW/4kHz)	-23.6	-18.1	-23.6
Tx E/S Antenna Gain (60% eff.)	(dB)	34.3	34.3	34.3
Tx E/S EIRP per Carrier	(dBW)	38.6	44.1	38.6
Atmospheric and Other Losses	(dB)	0.5	6.0	0.5
Free Space Loss	(dB)	205.4	205.4	205.4
Satellite:				
Total PFD at Satellite	(dBW/m2)	-122.7	-122.7	-122.7
Satellite Rx Gain towards Tx E/S (edge)	(dBi)	35.0	35.0	35.0
Received Signal Power	(dBW)	-132.3	-132.3	-132.3
Satellite Receive System Noise Temperature	(K)	600	600	600
Satellite G/T towards Tx E/S (edge)	(dB/K)	7.2	7.2	7.2
Satellite Channel Gain	(dB)	120.0	120.0	120.0
Satellite Tx Power	(Watts)	0.060	0.060	0.060
Satellite Tx Gain towards Rx E/S (edge)	(dBi)	30.0	30.0	30.0
Satellite Tx EIRP towards Rx E/S (edge)	(dBW)	17.7	17.7	17.7
Downlink (per carrier):				
Carrier Frequency	(MHz)	3,950	3,950	3,950
Atmospheric and Other Losses	(dB)	0.2	0.2	3.0
Free Space Loss	(dB)	194.2	194.2	194.2
PFD at Earth's Surface (in 4 kHz)	(dBW/m^2/4kHz)	-168.3	-168.3	-171.1
Rx E/S Antenna Diameter	(m)	5.00	5.00	5.00
Rx E/S Antenna Gain (60% eff.)	(dB)	44.1	44.1	44.1
Rx E/S G/T	(dB/K)	25.1	25.1	24.1
System (LNA+Sky) Noise Temp.	(K)	80	80	100
Total Link:				
Information Bit Rate (w/o coding)	(kbps)	2,000	2,000	2,000
FEC Rate	(fraction)	1/2	1/2	1/2
Modulation Type	(? PSK)	QPSK	QPSK	QPSK
Rx filter "alpha" factor	(%)	25.0	25.0	25.0
Carrier Noise Bandwidth	(kHz)	2,500	2,500	2,500
(C/N) - Thermal Uplink	(dB)	4.6	4.6	4.6
(C/N) - Thermal Downlink	(dB)	13.0	13.0	9.2
(C/I) - Intermodulation Noise	(dB)	22.0	22.0	22.0
(C/I) - Cross-Polar Interference	(dB)	25.0	25.0	25.0
(C/I) - Multi-Beam Effects	(dB)	18.0	18.0	18.0
(C/N+I) - Total Actual	(dB)	3.7	3.7	3.1
(Eb/No) - Total Actual	(dB)	4.7	4.7	4.0
(Eb/No) - Total Required	(dB)	4.0	4.0	4.0
Excess Margin	(dB)	0.7	0.7	0.0

Table 3.9-6: TT&C Link Budgets

VIRGO Link Budget

TT&C Uplink and Downlink

Earth stations: Tx & Rx (5m)

32Kbps / 1/2 FEC / QPSK Modulation / Alpha = 25

Link Parameters		Lower Uplink	Upper Uplink	Lower Downlink	Upper Downlink
Link Geometry:					
Tx E/S Range to Satellite (max)	(km)	31,150	31,151	31150	31150
Rx E/S Range to Satellite (max)	(km)	31,150	31,151	31150	31150
Uplink (per carrier):					
Carrier Frequency	(MHz)	5.926	6.424		
Tx E/S Antenna Diameter	(m)	5.0	5.0		
Tx E/S Power to Antenna	(W)	5.0	5.0		
Tx E/S PSD to Antenna - per 4 kHz	(dBW/4kHz)	-3.0	-3.0		
Tx E/S PSD to Antenna - per Hz	(dBW/Hz)	-39.0	-39.0		
Tx E/S Antenna Gain (60% eff.)	(dB)	47.6	48.3		
Tx E/S EIRP per Carrier	(dBW)	54.6	55.3		
Atmospheric and Other Losses	(dB)	2.0	2.0		
Free Space Loss	(dB)	197.8	198.5		
Spreading Loss	(dB)	160.9	160.9		
Satellite:					
Total PFD at Satellite	(dBW/m2)	-108.3	-107.6		
Satellite Rx Gain towards Tx E/S (beam edge)	(dBi)	0.0	0.0		
Effective Aperture of Receive Antenna	(dB-m^2)	-36.9	-37.6		
Received Signal Power	(dBW)	-145.2	-145.2		
Received Signal Power	(dBW)	-145.2	-145.2		
Satellite Receive System Noise Temperature	(K)	350	350		
Satellite G/T towards Tx E/S (beam edge)	(dB/K)	-25.4	-25.4		
(C/T) Thermal Uplink	(dBW/K)	-170.6	-170.6		
Satellite Channel Gain	(dB)				
Satellite Tx Power	(Watts)			1.5	1.5
Satellite Tx Gain towards Rx E/S (beam edge)	(dBi)			0.0	0.0
Satellite Tx EIRP towards Rx E/S (beam edge)	(dBW)			1.8	1.8
Downlink (per carrier):					
Carrier Frequency	(MHz)			3.701	4.199
Atmospheric and Other Losses	(dB)			2.0	2.0
Free Space Loss	(dB)			193.7	194.8
Spreading Loss	(dB)			160.9	160.9
PFD at Earth's Surface (in 4 kHz)	(dBW/m^2/4kHz)			-168.1	-168.1
Rx E/S Antenna Diameter	(m)			5.00	5.00
Rx E/S Antenna Gain (60% eff.)	(dB)			43.5	44.6
Rx E/S G/T	(dB/K)			23.1	24.2
Received Signal Power	(dBW)			-150.4	-150.4
System (LNA+Sky) Noise Temp.	(K)			110	110
(C/T) Thermal Downlink	(dBW/K)			-170.8	-170.8
Total Link:					
Information Bit Rate (w/o coding)	(kbps)	32.0	32.0	32.0	32.0
FEC Rate	(fraction)	1/2	1/2	1/2	1/2
Modulation Type	(? PSK)	QPSK	QPSK	QPSK	QPSK
Rx filter "alpha" factor	(%)	25.0	25.0	25.0	25.0
Carrier Noise Bandwidth	(kHz)	40	40	40	40
(C/N) - Thermal Uplink	(dB)	12.0	12.0		
(C/N) - Thermal Downlink	(dB)			11.8	11.8
(C/I) - Intermodulation Noise	(dB)	22.0	22.0	22.0	22.0
(C/I) - Cross-Polar Interference	(dB)	25.0	25.0	25.0	25.0
(C/I) - Multi-Beam Effects	(dB)	25.0	25.0	25.0	25.0
(C/N+I) - Total Actual	(dB)	11.2	11.2	11.0	11.0
(Eb/No) - Total Actual	(dB)	12.2	12.2	12.0	12.0
(Eb/No) - Total Required	(dB)	8.0	8.0	8.0	8.0
Excess Margin	(dB)	4.2	4.2	4.0	4.0

3.10 POWER FLUX DENSITY LIMITS

3.10.1 Downlink Communications Bands

The following Power Flux Density ("PFD") limits, applicable to the frequency bands proposed for use in the VIRGO™ System, exist in 25.208 of the Commission's Rules or in Table S21-4 of the ITU Radio Regulations, as measured at the surface of the Earth:

3.7-4.2 GHz	Between –142 and –152 dBw/m^2/4kHz as a function of elevation angle;
11.2-11.7 GHz:	Between –140 and -150 dBW/m^2/4kHz as function of elevation angle (FCC limits only in 11.45-11.7 GHz);
11.7-12.7 GHz:	Between –138 and -148 dBW/m^2/4kHz as function of elevation angle (No FCC limit in the 12.2-12.7 GHz band).

The maximum Ku-band PFD level at the surface of the Earth in the VIRGO™ system occurs in the user terminal downlink bands, with a value of -151 dBW/m^2/4kHz (see Section 3.6.1 above). In the C-band the maximum PFD level in the VIRGO™ System is –165 dBW/m^2/4kHz. These are less than even the most stringent of the relevant PFD limits existing in the FCC rules or ITU Radio Regulations so compliance with the PFD limits is assured.

3.10.2 TT&C PFD Limits

The VIRGO™ satellite's TT&C downlinks will operate below –160 dBW/m^2/4kHz at all times. At most times, at the higher altitudes and longer slant ranges, these downlinks will operate at PFDs at significantly lower levels. reaching –168 dBW/m^2/4kHz at apogee for low elevation angles, as shown in the TT&C link budgets. VIRGO™ will be constrained to remain always below the mandated PFD levels as cited in Section 3.10.1 above.

3.11 TRANSMIT-RECEIVE CONNECTIVITY

The connectivity of the uplink and downlinks of the VIRGO™ system are incidentally given in Sections 3.4.2.1, 3.4.2.2 and 3.4.2.3 above, where the frequency plans of the system are described. All uplinks from gateway beams are connected to downlinks in user beams, and vice versa. The only exception to this is for sub-channels originating from or destined to either user or gateway beams, which have the option of being switched through the ISL's to connect with active VIRGO™ satellites in other regions of the world (the exact configuration of the ISL-switchable channels has not yet been defined).

Although the frequency plan and beam configuration define the apportionment of spectrum to gateway and user beams, the use of active phased array satellite antennas in the VIRGO™ system means that the particular location of the uplink and downlink beams on the Earth's surface is fully flexible. Therefore it is not, for example, possible to uniquely define which 750 MHz portions of the user downlink spectrum will be transmitted towards a particular point on the Earth's surface.

3.12 INTRA-SYSTEM INTERFERENCE

Intra-system interference arises within the VIRGO™ system from a variety of sources, most of which are the same as in conventional GSO satellite systems. These GSO-like sources of intra-system interference are as follows:

- Intermodulation noise resulting from the use of multiple carriers within the operating bandwidth of the satellite channel, which although extremely linear, is not perfect in this respect. The use of solid-state power amplifiers within the satellite active phased array antenna means that this system degrader is minimized. The effect is also minimized by careful setting of the relative carrier power levels, which is achieved by the management control of the gateways for both outbound and inbound transmissions. Allowance is made for intermodulation noise in the link budgets given in Section 3.9.

- Cross-polar interference arises from the use of orthogonal polarizations within overlapping frequency bands (in the case of the VIRGO™ system these are left-hand circular and right-hand circular polarizations). All antennas, both satellite and earth station, achieve only a finite rejection of the orthogonal polarization. In the case of the user terminal beams, only a single polarization is used within a beam, but the adjacent beams, in some cases, will be co-frequency and cross-polar. Therefore, the worst cross-polar interference will occur for the user beams at certain parts of the edges of those beams. The situation for the user beams is therefore somewhat better than for a conventional dual polarization GSO satellite system. The gateway beams, on the other hand, operate co-frequency with dual orthogonal polarizations. Allowance is made for cross-polar interference in the link budgets given in Section 3.9.
- Adjacent channel interference arises due to out-of-band emissions producing interfering signal energy within the receive bandwidth of adjacent channels. In the case of the VIRGO™ system, which uses wideband satellite channels, this effect is controlled by ensuring adequate channel filtering of the signals by the transmitting earth stations, operation of the satellite channel in a linear mode (so that spectrum re-growth is minimized) and by the use of adequate guard bands between transmissions. This effect is generally catered for by the above allowances for intermodulation and cross-polar degradation effects.

In addition to the above GSO-like sources of intra-system interference, the use of multiple co-frequency spot beams in the VIRGO™ system gives rise to additional effects, as follows:

- On the downlink the sidelobes of the other co-frequency co-polar downlink spot beams produce interference into the wanted downlink spot beam. On the uplink the transmissions from uplink earth stations operating in other co-frequency co-polar uplink spot beams produce interference into the sidelobes of the wanted uplink spot beam. These effects are controlled in the VIRGO™ system by ensuring the best possible sidelobe performance of both receive and transmit spot beams is achieved, together with appropriate geographic spacing of simultaneously operating co-frequency co-polar spot beams. Nevertheless, the resulting link degradation due to this effect is significant, particularly for links at the edges of the spot beams, and has been taken account of in the link budgets given in Section 3.9.

3.13 INTER-SYSTEM INTERFERENCE

The VIRGO™ system provides significant benefits, compared to other proposed NGSO FSS systems, in terms of its spectrum sharing capability with other services. The key differentiating factors, which derive from the novel design of the satellite constellation, are discussed and quantified in this section.

3.13.1 GSO FSS and BSS

The world satellite community is acutely aware of the current debate in the ITU concerning the operation of NGSO satellite systems in frequency bands used, or planned to be used, by GSO satellite systems. This keen interest in accommodating NGSO systems originated at WARC-92 and WRC-95 with U.S.-led initiatives, and culminated at WRC-97 with the introduction of provisional EPFD and APFD limits into the ITU Radio Regulations that are intended to protect GSO systems against unacceptable interference from NGSO systems [9]. Since WRC97 the ITU Joint Task Group ("JTG") 4-9-11, in which the U.S. is an active participant, has been studying and debating the issues of interference between NGSO and GSO systems, and it is tasked with presenting its conclusions for consideration by WRC-2000. In the work of the JTG 4-9-11 group so far, there is a clear polarization between the "GSO" proponents and the "NGSO" proponents, with both sides expressing their concern about the provisional limits, and possible changes to these limits. The setting of these limits is clearly a crucial and difficult matter in order to avoid either allowing unacceptable interference into GSO systems, or constraining NGSO systems to the point that they are technically and economically not feasible. Conventional NGSO systems, using circular orbits, are clearly finding it difficult to reach agreement on conditions to allow co-frequency sharing with GSOs.

By contrast, the proposed VIRGO™ system uses a different approach to NGSO system design. The use of elliptical inclined orbits (see Section 3.2) with active arcs near to their apogee creates a completely different sharing environment with respect to GSO satellite systems. By careful design of the VIRGO™ satellite constellation, it has been possible to achieve a large angular separation between the active VIRGO™ satellites and the GSO orbit, which never drops below 40°. This compares with the 5° to 10° GSO orbit avoidance that other NGSO systems operating in circular orbits are proposing.

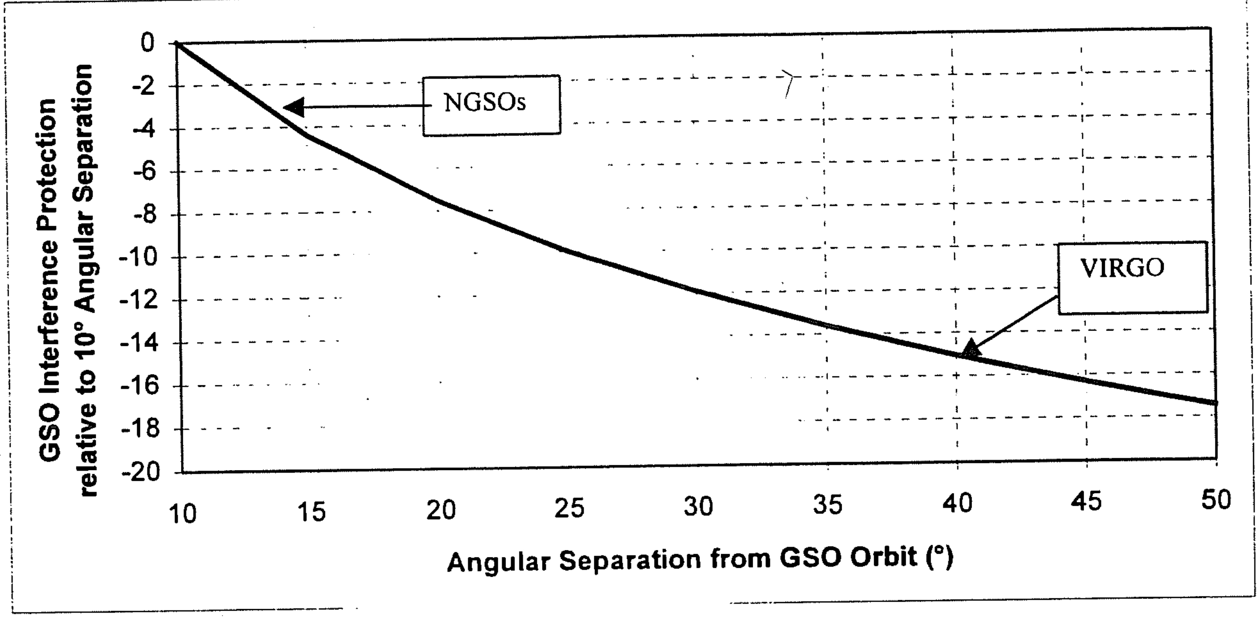
Figure 3.13.1-1 demonstrates the additional interference protection that arises from increased angular separation from the GSO orbit. The data in this diagram is based on the "25log(θ)" roll-off of the GSO and VIRGO™ earth station antenna gain characteristics, which is

---

[9] EPFD and APFD limits are defined in S.22 of the ITU Radio Regulations.

typically valid out to the 48° off-axis point. The reference point in Figure 3.13.1-1 is the 10° GSO orbit avoidance situation, as proposed by some NGSO systems (others have proposed even less than 10°). Relative to this reference, the increase to 40° GSO orbit avoidance provides an additional 15 dB of interference protection. This additional protection is to the benefit of both the GSO and NGSO system operators, as it reduces the interference in both directions. This 15 dB reduction in NGSO-to-GSO interference (as well as in GSO-to-NGSO interference) effectively means that there is no interference problem between the VIRGO™ system and existing or planned GSO systems operating co-frequency and co-coverage.

Figure 3.13.1-1:
Additional Interference Protection with Respect to GSO Systems Arising from Increased Angular Separation of the Active NGSO Satellite from the GSO Orbit



An equally important advantage of the VIRGO™ system design results from the fact that no communications transmissions to or from the VIRGO™ satellites take place when a VIRGO™ satellite is closer to the GSO orbit than 40°, unlike the operating mode of the circular orbiting NGSO proposals. These other NGSO systems have to maintain transmissions to and from other beams in their coverage area, even while passing through the GSO exclusion zone for a particular set of beams. If this were not the case their satellites would be unusable for the vast majority of their orbits, a situation made worse by the fact that their satellites would actually be unusable in parts of their orbit where they are most needed for communications traffic (equatorial and moderate latitudes). Because these other NGSO systems operate in this way they cause high levels of downlink interference from the NGSO satellite antenna sidelobes to GSO systems for short periods of time as the NGSO satellite passes through the line-of-sight between GSO satellites and their associated earth stations (the so-called "short-term" interference). There is no such interference effect from the VIRGO™ satellite system into GSO systems.

In short, the VIRGO™ system simply does not cause any in-line interference events into GSO satellite networks and therefore will easily meet the likely short-term interference criteria to be adopted by the ITU. This is particularly important as it is the short-term interference resulting from in-line interference events caused by other NGSO systems that has presented the most difficult problem to the GSO operators during the work of the JTG 4-9-11 so far.

Tables 3.13.1-1 to 3.13.1-3 give simple, yet accurate, assessments of the downlink interference from a VIRGO™ satellite into a GSO receive earth station. The analysis pessimistically assumes three simultaneously interfering VIRGO™ satellites because there may be satellites from three VIRGO™ sub-constellations visible to a GSO earth station at a time within each region, although it is very unlikely that all three satellites will be at the minimum separation angle of 40 degrees assumed here. The only situation where the number of simultaneously active and visible VIRGO™ satellites might increase to four is as follows:

- During the brief handover from a "setting" to a "rising" VIRGO™ satellite, which will occur for several seconds once every 4.8 hours. During this time the chances of both VIRGO™ satellites being at the minimum 40° GSO separation angle as viewed from the GSO earth station is exceedingly small. Even if such a situation were to occur it would give rise to an increase of less than 1.3 dB compared to the situation where three visible VIRGO™ satellites are assumed, which would still maintain the aggregate VIRGO™ interference levels to a very low level.

In Tables 3.13.1-1 to 3.13.1-3 the analysis starts with the maximum downlink PFD of the VIRGO™ satellite, as given in Section 3.6 above. Note that the maximum downlink PFD occurs only in the 11.2-12.7 GHz user terminal band only. In the gateway downlink bands the maximum PFD, and hence the potential interference to GSO systems, is considerably less. Then based on the minimum 40° GSO orbit avoidance angle, the gain of the GSO receive earth station antenna is calculated based on the 32-25log(θ) mask of 25.209 of the FCC rules (as well as in ITU-R Recommendation S.465-5). This gives a GSO earth station antenna gain towards the VIRGO™ satellite of less than –8.1 dBi for all frequency bands. This gain is converted to an Effective Aperture (in dB-m^2) using an appropriate receive frequency. The use of the Effective Aperture then allows a simple calculation of the received interfering signal power, in a 4 kHz bandwidth, from a single VIRGO™ satellite. After allowing for three simultaneously visible VIRGO™ satellites, and adjusting to a reference bandwidth of one Hz, this aggregate interfering signal power is compared to the inherent noise power of the GSO receiver. In this case we have used very optimistic assessments of the likely GSO receive system noise temperatures for the various frequency bands (i.e., 125 K at Ku-band and 80 K at C-band), which is to the benefit of the GSO system. Based on this the interference-to-noise power density ratio (I_0/N_0) is calculated, which is also expressed as an equivalent ΔT/T degradation to the GSO receive earth station performance.

The results in Tables 3.13.1-1 to 3.13.1-3 clearly show that the effect of the VIRGO™ satellite interference is completely unnoticeable. In fact it is questionable whether I_0/N_0 ratios as low as those calculated could even be measured. The interfering signal power is less than one three-hundredth of the noise power due to the LNA (Low Noise Amplifier) of the GSO receive earth station, and in some cases is lower than one two-thousandth.

Table 3.13.1-1: **Analysis of Worst-Case Downlink Interference from VIRGO™ Satellite Into GSO Earth Station in the 11.2-12.7 GHz Frequency Band**

Maximum PFD of VIRGO™ satellite in 4 kHz	**-151**	**dBW / m^2 / 4kHz**
GSO orbit avoidance angle	**40**	**°**
GSO Rx Earth Station gain towards VIRGO™ satellite	-8.1	dBi
Frequency	12000	MHz
Effective Aperture of GSO Rx Earth Station towards VIRGO™ satellite	-51.1	dB-m^2
GSO Rx Earth Station Interfering Signal Power in 4 kHz (per VIRGO™ satellite)	-202.1	dBW / 4kHz
GSO Rx Earth Station Interfering Signal Power Spectral Density (per VIRGO™ satellite)	-238.1	dBW / Hz
Increase in interference due to 3 simultaneously visible VIRGO™ satellites	4.8	dB
GSO Rx Earth Station Interfering Signal Power Spectral Density (3 VIRGO™ satellites)	-233.3	dBW / Hz
GSO Rx Earth Station System Noise Temperature	**125**	**K**
GSO Rx Earth Station System Noise Power Spectral Density	-207.6	dBW / Hz
I_0/N_0 at GSO Rx Earth Station Input	**-25.7**	**dB**
ΔT/T Degradation to GSO Rx Earth Station	**0.271%**	

Table 3.13.1-2: Analysis of Worst-Case Downlink Interference from VIRGO™ Satellite Into GSO Earth Station in the 10.7-11.2 GHz Frequency Band

Maximum PFD of VIRGO™ satellite in 4 kHz	**-160**	**dBW / m^2 / 4kHz**
GSO orbit avoidance angle	**40**	°
GSO Rx Earth Station gain towards VIRGO™ satellite	-8.1	dBi
Frequency	11000	MHz
Effective Aperture of GSO Rx Earth Station towards VIRGO™ satellite	-50.3	dB-m^2
GSO Rx Earth Station Interfering Signal Power in 4 kHz (per VIRGO™ satellite)	-210.3	dBW / 4kHz
GSO Rx Earth Station Interfering Signal Power Spectral Density (per VIRGO™ satellite)	-246.3	dBW / Hz
Increase in interference due to 3 simultaneously visible VIRGO™ satellites	4.8	dB
GSO Rx Earth Station Interfering Signal Power Spectral Density (3 VIRGO™ satellites)	-241.5	dBW / Hz
GSO Rx Earth Station System Noise Temperature	**125**	**K**
GSO Rx Earth Station System Noise Power Spectral Density	-207.6	dBW / Hz
I_0/N_0 at GSO Rx Earth Station Input	**-33.9**	**dB**
ΔT/T Degradation to GSO Rx Earth Station	**0.041%**	

Table 3.13.1-3: Analysis of Worst-Case Downlink Interference from VIRGO™ Satellite Into GSO Earth Station in the 3.7-4.2 GHz Frequency Band

Maximum PFD of VIRGO™ satellite in 4 kHz	**-165**	**dBW / m^2 / 4kHz**
GSO orbit avoidance angle	**40**	°
GSO Rx Earth Station gain towards VIRGO™ satellite	-8.1	dBi
Frequency	4000	MHz
Effective Aperture of GSO Rx Earth Station towards VIRGO™ satellite	-41.5	dB-m^2
GSO Rx Earth Station Interfering Signal Power in 4 kHz	-206.5	dBW / 4kHz
GSO Rx Earth Station Interfering Signal Power Spectral Density	-242.6	dBW / Hz
Increase in interference due to 3 simultaneously visible VIRGO™ satellites	4.8	dB
GSO Rx Earth Station Interfering Signal Power Spectral Density (3 VIRGO™ satellites)	-237.8	dBW / Hz
GSO Rx Earth Station System Noise Temperature	**80**	**K**
GSO Rx Earth Station System Noise Power Spectral Density	-209.6	dBW / Hz
I_0/N_0 at GSO Rx Earth Station Input	**-28.2**	**dB**
ΔT/T Degradation to GSO Rx Earth Station	**0.152%**	

It is useful to compare the Ku-band EPFD levels (according to the definitions in ITU-R S.22) of the VIRGO™ system with the provisional S.22 EPFD limits adopted at WRC97, as shown in Table 3.13.1-4. The VIRGO™ EPFD levels in this table are derived for the user terminal frequency band 11.2-12.7 GHz, where the downlink PFD levels are the greatest. The results in the gateway downlink band 10.7-11.2 GHz would be 9 dB better because of the use of lower downlink PFD for gateway beams. In this table both the long-term and short-term provisional WRC97 EPFD limits are given, together with an indication of whether these apply in the BSS or FSS allocations. The VIRGO™ EPFD levels are given for two cases of three or four VIRGO™ satellites simultaneously visible.