THE HUMRLE SPACE TELESCOPE: THE ACCOMMODATION OF A SMALL ASTRONOMICAL TELESCOPE ON THE MINISIL BUS

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ABSTRACT

Humble Space Telescope mission is intended to provide astronomers with high quality images from a small astronomical telescope placed in Earth orbit. The success of the Hubble Space Telescope is well documented although its inherent drawback is that investigators may have to wait several years until the schedules allow for their observations. Humble is intended to provide a much more rapid response time for users requiring less demanding images than Hubble, but still wanting to overcome the severe limitations placed on astronomers by the Earth's atmosphere. The MiniSIL small satellite bus, designed and built by Space Innovations Limited (SIL), is a semi-standardised system comprising S-band uplink and X-band downlink communications at rates up to 10Msps for the downlink, attitude sensing and control to 0.1° or better, power conversion and distribution, and on-board data handling including sizeable solid state memory devices. It is inherently modular and readily adaptable to different satellite configurations. MiniSIL is an ideal platform for Humble as it combines high performance with relatively low cost. The spacecraft would use the full suite of SIL sub-systems integrated with a 25cm astronomical telescope. The detectors for the spacecraft will allow a wide range of scientific studies to be conducted, and the flexible and low-cost ground system proposed will ensure that data is with the investigator within minutes of it being transmitted by the satellite.

INTRODUCTION

There is currently a large gap between the quality of facilities available to large organisations and the smaller groups of users, such as amateur astronomers and educational institutions, who make do with a limited range of ground-based services. In order to satisfy demands for a better service, which will be of high educational and research value and also to help encourage the growing public interest in the space sector, the Humble project aims to provide a small telescope, on board a MiniSIL satellite bus, coupled with a ground station and readily accessible data distribution channels.

The project was originally conceived by Dr Michael Martin-Smith in response to a national call for proposals for Millennium Projects and is being carried out by Space Innovations Limited (SIL). The UK Department of Trade and Industry (DTI) is already partially financing the Qualification Model of the

MiniSIL which is to carry the Humble payload via its Sector Challenge initiative.

Humble will provide images of the universe in the visible and ultra violet spectrum. Images in the visible spectrum taken by Humble's telescope in its low Earth orbit (LEO) will provide a regular and reliable source of high quality data for researchers and amateur astronomers, unencumbered by weather conditions or other atmospheric disadvantages. The UV spectrum images will provide a completely new opportunity for many users to investigate this aspect of the universe.

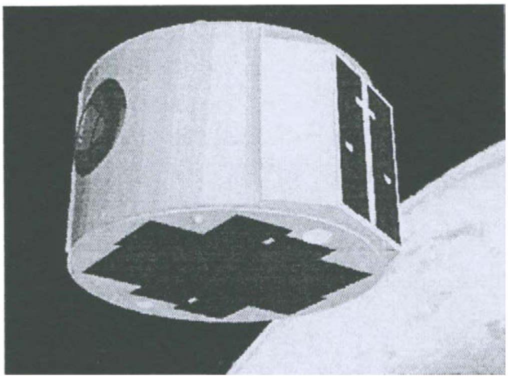


Figure 1. A graphic representation of Humble in orbit.

The service will be available to anyone with access to the Internet. Users will simply send their requests via e-mail to the Operations Control Centre where imaging schedules will be drawn up. Individuals will receive notification of the success of their application and details of when the imaging is expected to take place.

As is the case with the Hubble Space Telescope and large ground based telescopes, the services of Humble are expected to be heavily over-subscribed. A fixed percentage of observation time will be allocated to satisfy individual amateur astronomers, with another time-slice allocated to schools and colleges and the remainder allocated to higher educational institutions and researchers. Whilst the services of Humble will be available to users across the globe, preference will of course be given to applications received from countries who have contributed to the design and development of the Humble mission. At present the Humble programme is entirely a UK mission.

Humble is being designed for a three-year lifetime, although there are no components strictly limiting it to this life span. During this lifetime it will provide visible and ultraviolet images, as well as supporting an additional range of payloads which are yet to be determined. MiniSIL-P, a variant of the SIL-designed mini-satellite platform, MiniSIL, was chosen for Humble. The design incorporates a load bearing structure with a pair of standard or adapted interface rings, allowing it to be placed in a stacked configuration on launchers of the Pegasus class or larger, or launched on an Ariane 5 ASAP, thus greatly increasing launch opportunities and minimising launch costs. The baseline orbit is assumed to be a circular 800km orbit with an 80° inclination, but the overall design is capable of comfortably accommodating a wide range of orbits. The final orbit will depend on the chosen launch as Humble will not carry a propulsion system to allow for orbit manoeuvres. Attitude manoeuvres will regulate the imager's pointing direction, as it will be spacecraft fixed, as well as providing pointing capabilities during ground passes to allow for greater data rates on the downlink. Images, other payload data and house-keeping data, will be stored in a solid state mass memory and later transmitted to the ground station via the X-band downlink. The uplink will use an S-band frequency. The MiniSIL satellite bus, provides an adaptable semi-standardised platform from which to develop the spacecraft design. Most of the subsystems on the platform are semi-standard or standard off-the-shelf SIL systems and are detailed in the following sections.

THE HUMBLE MISSION

The need for more access to space telescopes is evident, however Humble proposes some more unique advantages to its users. The telescope will be space-based, this has several distinct advantages over its ground-based counterparts: Firstly, it is unencumbered by the Earth's atmosphere, which hinders certain wavelengths such as ultraviolet and also X-ray and gamma rays. It will also provide live pictures to schools during daylight hours. At the higher end of the education scale, students and others carrying out projects with limited time scales will be able to access their desired targets in shorter time scales. The Humble telescope will feature quicker request response time than the Hubble telescope as well as being suitable for targets not deemed important enough for the Hubble's overloaded schedule. It will also help support some of the work left off by the International Ultraviolet Explorer (IUE).

The telescope and satellite performance will limit the overall project capabilities, however much useful work will be carried out and the schedule is expected to be heavily subscribed to. The telescope will be used to obtain images of stars and planets, discover new asteroids or comets (well rewarded by the Benson prize), carry out 1 to 2 minute duration photometry and search for extra-solar-system planets. Some more specific projects, such as the study of putative dust clouds in the Earth Moon L4,L5 points and studies on stars, not interrupted by the Earth's rotation. The coupling of UV and visible wavelengths will allow simultaneous views across frequencies of any targeted objects, and may allow for wide spectrum bolometry and fascinating images to help raise the profile of this field.

HUMBLE SATELLITE PLATFORM

MiniSIL Satellite Structure

Humble's structural design makes use of SIL's MiniSIL, a standard mini-satellite platform suitable for applications in the 100-400 kg range. There are two types of MiniSIL, MiniSIL-P, designed for narrow fairing Pegasus class launchers, or the wider MiniSIL-L, which is suitable for wider launch vehicles allowing an increase in surface area and payload volume. Both these buses are available in spinning or 3-axis stabilised configurations. The current design is based on the former, a 3-axis stabilised MiniSIL-P. Should the additional payloads necessitate a larger volume or power supply the design may be adapted to a MiniSIL-L with relative ease.

The primary structure constitutes an aluminium alloy thrust tube, stiffened by stringers, and a pair of V-band interfaces that make MiniSIL compatible with almost all launch vehicles in use today. The use of a load bearing structure allows the satellite to be launched in a stacked configuration as a secondary passenger and is also adaptable for the Ariane 5 ASAP. This results in a significant reduction in costs whilst retaining its suitability for a wide range of launch opportunities. In the case of Humble, the thrust tube incorporates a relatively large diameter hole to mount the telescope radially, allowing it to look out the side of the spacecraft. This is the more favourable option not only for telescope design but also for power performance profiles available from the solar arrays during typical Humble pointing scenarios. In the case of a nadir pointing imaging mission a typical imager would usually be accommodated axially to point from the upper or lower closure panel which would form the nadir pointing face of the MiniSIL.

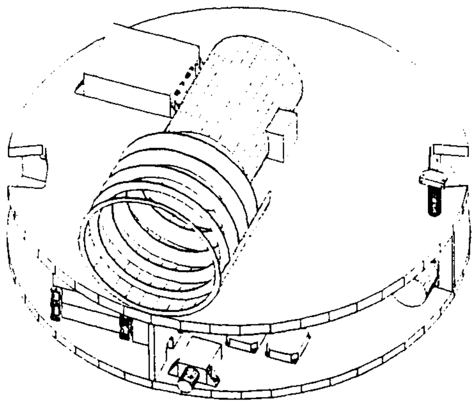


Figure 2. The MiniSIL secondary structure and sub-systems with the Humble payload.

The subsystems and payloads are accommodated on opposite sides of an Aluminium honeycomb shelf. Two more Aluminium honeycomb panels are used to enclose the volume inside the thrust tube.

This set-up allows the payload area to be a mono-volume dedicated solely to the payload and also allows the payload to be integrated separately from the platform sub-systems during the Assembly, Integration and Test (AIT) phase. The third large panel encloses the payload volume, on top of which antennas and attitude sensors may be placed.

The solar arrays are mounted on four side panels around the thrust tube circumference and on the outside surface of the top shelf. The adopted solar array configuration can be clearly seen in Figure 3. The side panels are mounted opposite the telescope aperture.

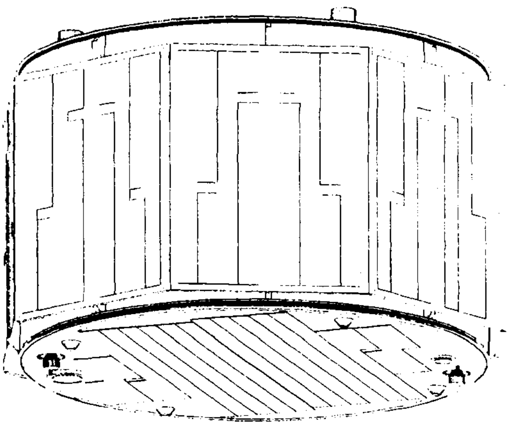


Figure 3. Humble Solar Array Configuration.

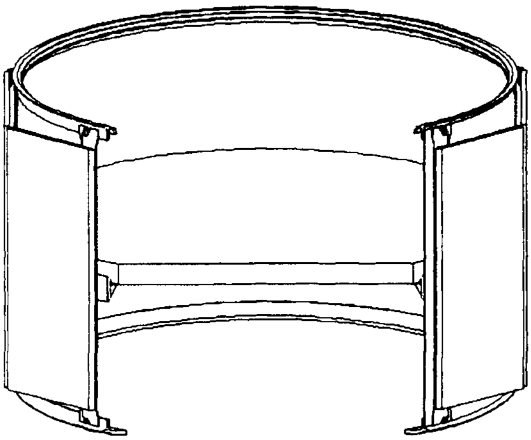


Figure 4. MiniSIL-P basic structure cut-through.

Alternatives using a MiniSIL-L, 2P or 2L may be considered. The MiniSIL-L has shear panels set further out from the thrust tube allowing sub-system accommodation outside the tube and allowing the entire volume within the thrust tube to be dedicated to payload. This version also provides an increased usable solar array area. The MiniSIL-2 series have increased spacecraft height, improving both payload volume and available array power. As already mentioned, however, MiniSIL-P provides more than enough resources to satisfy the Humble imaging payload alone and other versions will be considered only if additional payload requirements dictate such a need. Shown in Figure 5 below is the approximate mass distribution for the Humble spacecraft, including an assumed 50kg of additional payload.

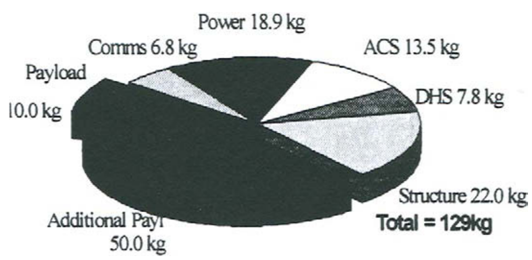


Figure 5. Mass distribution on Humble, including an estimated 50kg additional payload.

Overall Systems Design

The Humble mission utilises a standard MiniSIL satellite bus and subsystems. The various subsystems are, in general, standard SIL designs with most changes in general restricted to the Attitude Control System (ACS), due to its key role in most aspects of the satellite's mission.

The ACS is responsible for pointing the imager and providing pointing knowledge during imaging sessions, as well as pointing the X-band antennas during downlink operations and, finally, ensuring the desired pointing of the solar arrays so as to ensure a constant high power supply. The physical accommodation of the systems to be used in Humble is illustrated in Figure 6 above.

The Humble electrical system block diagram is given in Figure 7 below and a brief description of each of the systems follows.

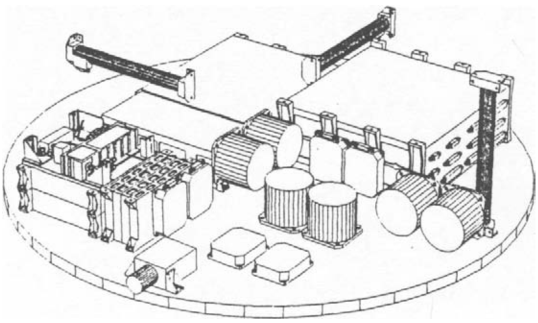


Figure 6. A schematic of the Humble systems shelf showing the various subsystems.

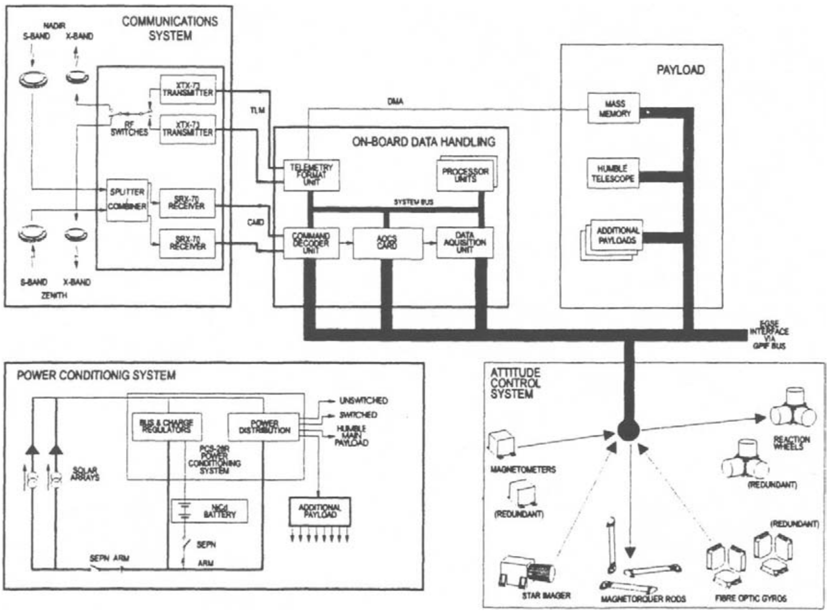


Figure 7. Electrical Systems Block Diagram.

Communications

The uplink uses S-band, whereas the downlink will make use of an X-band link set at around 8500 MHz, allowing the high data rates desirable for the transfer of images and other payload data.

The stored data will be formatted following the CCSDS packet standard recommendations by the DHS Telemetry Format Unit (TFU) which will have a Direct Memory Access (DMA) link to the on-board mass memory enabling the necessary high speed, efficient transfer of data.

The X-band downlink will then relay both the payload data and the housekeeping data via a system using one of two cold redundant XTX-73 3W transmitters and two switchable X-band patch antennas, one nadir and one zenith facing. During these ground passes the attitude control system will ensure a pointing accuracy required for downlink data rates of around 10Msps.

The S-band uplink is a BPSK coded signal modulated on a subcarrier allowing data rates up to 4kbps. The signal will be received by one of two SPA-20 S-band patch antennas, one zenith and one nadir pointing, and follow through to two hot redundant SRX-70 receivers via a combiner/splitter.

The ground segment for the link will be based on the SIL-XGS series of small ground stations. This is covered in more detail later in this paper.

Command and Data Handling

The data handling will be carried out by a DHS-S32 data handling system, at the heart of which are two high performance 32-bit SPARC-based processor units. The system will process direct and time tagged commands and react to house keeping data. The Attitude Control Electronics (SACE) will also be accommodated within the DHS-S32.

The DHS-S32 will manage all on-board housekeeping and payload management duties. In the case of the Humble mission the usual internal Mass Memory Unit of the DHS will be replaced by a larger (5Gbit) separate external Mass Memory Unit. It will process, store and format data conforming to CCSDS Packet Telemetry and Telecommand Standards.

Power System

The backbone of the power system is the PCS-28R/200 power conditioning system (PCS), which will receive power from GaAs solar arrays when sunlit and the lithium ion battery during eclipses.

The PCS will sustain and regulate the power bus to within 2% of its nominal 28V voltage. It utilises a majority voting system of three controllers operating dual hot redundant charge/discharge regulators to supply a protected output to ten switched and four unswitched loads.

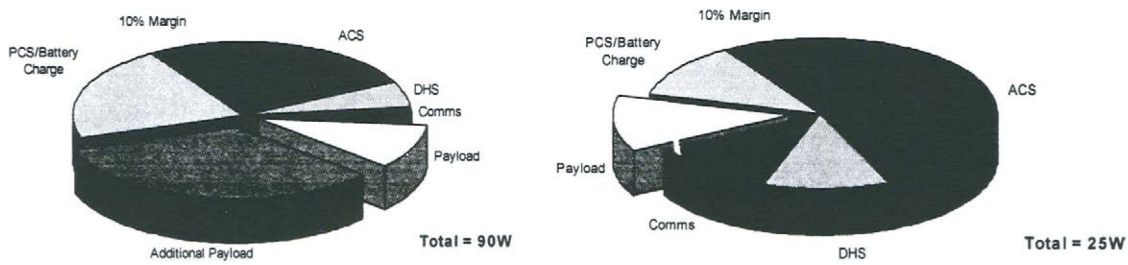


Figure 8. Left: Maximum power consumption during sunlit portion of orbit.
Right: Reduced power consumption while Humble is eclipsed.

The solar arrays, utilising strings of 37 GaAs cells, are mounted on the top side and wrapped around the rear side of the spacecraft. The top array is comprised of 13 strings and four 5-string panels form the rear side arrays, providing a combined output to the PCS of around 106W during peak power attitude at end of life. Due to the continuous attitude control employed by Humble the solar array configuration is independent from the chosen orbit.

The lithium ion batteries to be used provide a 4Ah capacity. Lithium ion technology offers the advantage of relatively fast charge rates and a high depth of discharge without detriment to the battery lifetime. Increased payload power consumption and duty cycles brought on by the additional payloads may necessitate the adoption of batteries with larger capacities and recharge rates.

The above pie charts illustrate some typical power usage scenarios for the Humble spacecraft. During eclipse payload operations are likely to be reduced or suspended for power efficiency reasons, although the present demands of the Humble payload will not preclude eclipse operations. Due to the operational pointing flexibility in the Humble mission it will be possible to provide significant flexibility in payload scheduling, including during eclipse, due to the opportunities to enter a 'recharge mode' with optimal solar array illumination if necessary. Operations during eclipse, however, will almost certainly result in the need to use a larger battery capacity, although until additional payload powers and operational scenarios can be estimated the baseline battery capacity of 4Ah is assumed sufficient for mission requirements.

Attitude Control System

Humble is a three axis stabilised design requiring continuous attitude control for its imaging, down link and recharging operations, as well as a high level of pointing accuracy and knowledge and low jitter needed for the imager. A star mapper aligned with the imager will provide accurate pointing information during imaging sequences, additional attitude information will be provided by fibre optic gyros and a magnetometer. Attitude manoeuvres will be performed by reaction wheels set in the three axes, fully backed by a further cold redundant set. Desaturation of the reaction wheels will be carried out using MTR-25 rod magnetorquers. Use of a GPS orbit determination system is being considered.

The attitude instruments are interfaced with the on-board data handling (OBDH) system via an attitude control electronics (SACE) card, accommodated within the OBDH box in place of the usual mass memory board. This is a departure from the usual configuration where the SACE is accommodated in a dedicated box and treated as a separate unit from the DHS. However, the electrical configuration will not change.

The SSM-20/2 star mapper comprises an optical head with a passively cooled 770x567 element CCD array and a space-rated SPARC processor unit, the latter being currently under development at SIL. It will be capable of a 3σ accuracy of 20 arcseconds within its 16° by 12° field of view with an update rate greater than 2Hz in mapping mode. The MFM-3L magnetometers will provide a field sensitivity of 250nT, although these magnetometers may be used in a Hi-Gain mode to allow greater sensitivity over a smaller range.

The reaction wheels will be desaturated using a combination of three MTR-25 magnetorquers aligned in each axis. Although the magnetorquers are not physically duplicated on the spacecraft, internal redundancy is provided by separate coils. Reaction wheels and fibre optic gyros will not be provided by SIL but are available in suitable form from a number of external suppliers.

PAYLOAD

The Humble telescope is the primary payload for the mission, others will be added to make full use of available resources and aid in the reduction of costs per user.

The Humble Telescope

The Humble payload consists of an imager coupled with a mass memory, used to store the large volume of data associated with images.

The imager itself is still in its early design stages and options are still being looked at; the current design is based around a 25cm (8") telescope with detectors for the visible and ultra violet spectrum. The telescope will be based on a space qualified ordinary Earth-bound astronomical telescope, and therefore be of relatively low-cost. Options include adding another low cost telescope or splitting the signal from one telescope to two detectors.

The images taken will be stored in the mass memory until the next ground pass. The solid state recorder will dedicate most of its 5Gbit for the images and other payload data, whilst allowing a small percentage for use by the satellite bus housekeeping data.

Other Payloads

Opportunities for additional payloads, to raise funds or other benefits for the project, are still open. The telescope will retain privileges of a primary user, thus additional users must be compatible with the Humble mission. The current bus design utilises the smallest MiniSIL variant, MiniSIL-P, although this may be replaced by a larger or higher power type should the need arise. However, the current payload mass of 80kg and peak power use of 60W are well within the MiniSIL-P design specifications.

Examples of expected payloads are debris sensors, radiation sensors, technology demonstration programmes and on-board experiments.

OPERATIONAL PERFORMANCE

Orbit

The orbit requirements for Humble remain flexible within the basic constraints of it being a circular Low Earth Orbit (LEO) with a high inclination; the exact details will depend on the launch opportunity selected. The baseline orbit assumed for design purposes is an 800km circular orbit inclined at 80°.

The orbit will typically allow two or three sunlit ground passes a day, each an average of around ten minutes, during which images and data from the on board experiments will be downloaded via the X-band link. Depending on operation scenarios and power usage it may also be feasible to transmit during eclipsed passes.

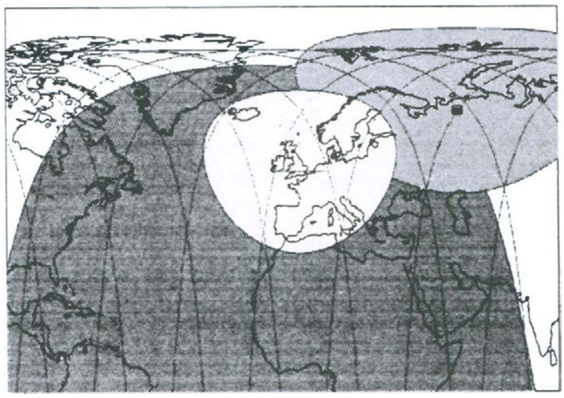
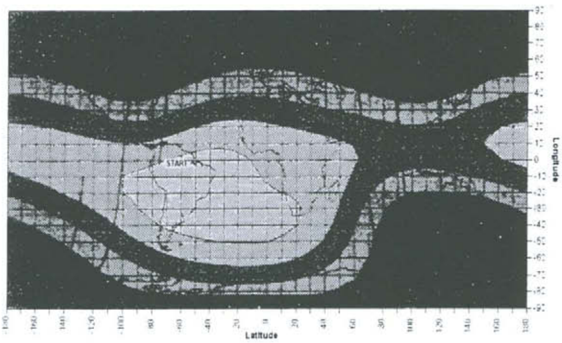


Figure 9. A likely groundtrack assuming 800km altitude and 80° inclined circular orbit. The chart shows the nightime zone, the satellite horizon and the ground mask.



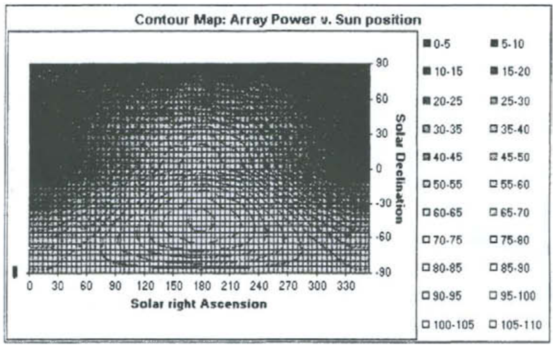


Figure 10. An orbit track together with a plot of the Earth's geomagnetic field strength as will be encountered by HUMBLE in an 800 km orbit, as generated using the SIL in-house software package SILMAG. [The model used is the International Geomagnetic Reference Field (IGRF 95)].

Figure 11. A plot of the power availability with respect to satellite attitude to the Sun.

Imager Operations

The imager is satellite fixed, pointing being achieved by use of the reaction wheels provided with accurate pointing knowledge by the star mapper.

The solar arrays are positioned so as to allow pointing in most directions whilst retaining some power output from the arrays. There are some attitudes relative to the sun which provide very low power, thus will be avoided during ordinary operation. The imager itself has an exclusion zone based around sun pointing angles to protect the sensitive imager. As the orientation of the imager is in an opposing direction to the rear side arrays much of the exclusion zone will overlap the low power attitude positions, hence the combined effect is limited. The regions affected by this exclusion zone will vary as the Earth revolves around the Sun, but will allow full sky coverage in the course of a year. Other constraints may be caused by the albedo from the Earth and the Moon although these will be much more temporary effects. As with other on-board equipment, imager activity may be stopped or limited during periods of eclipse.

GROUND SEGMENT

The ground station to be used for the Humble mission will be one of SIL's XGS series illustrated in Figure 12 below.

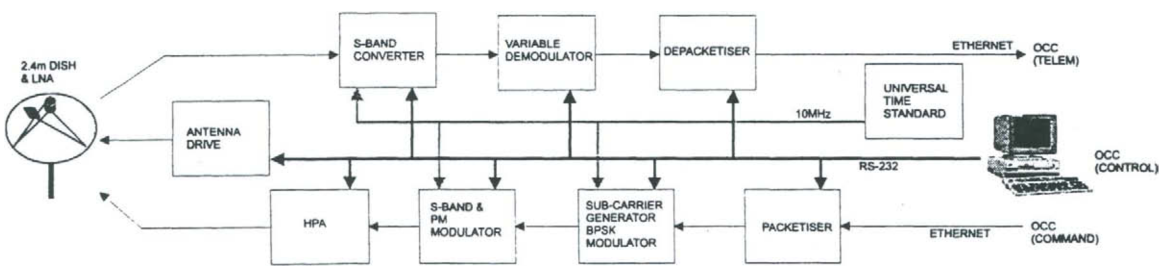


Figure 12. Ground Station Block Diagram.

Much of the heritage of the XGS series stations lies in SIL's currently available series of SGS low cost S-Band ground stations. The ground station for the Humble mission will be based in England and will be purpose built for the Humble mission, linked to an Operations Control Centre (OCC) and Science Operations Centre (SOC).

Housekeeping data will be distributed to the appropriate hosts within the OCC for real-time analysis whilst the payload data will be temporarily archived for processing and distribution after the pass. As soon as the pass is finished the Humble images will be processed in the SOC and distributed by e-mail to the persons who requested the data. Humble images will also be made available via the Internet. In a similar manner to the Humble image data, the data from the additional payloads will be temporarily archived in the OCC and distributed to the concerned parties after the pass.

CONCLUSIONS

This paper has recognised the many benefits of the Humble project and also demonstrated the feasibility of the mission. The project may be realised at low cost by means of a careful design process and use of semi-standardised systems on a standard platform and also by sharing the satellite platform with other payloads. The satellite platform described is capable of supporting a number of other payloads with considerable flexibility, although primary consideration will be given to the needs of the Humble Imager in operations.

The Humble project will provide a valuable addition to present astronomical facilities. The images, both in the visible and the ultra violet wavelengths will not only provide a valuable observing platform for scientific research but will be of immense value to students of all levels at educational institutions around the world. It will provide previously unimaginable opportunities for ordinary members of the general public to actively participate in and benefit directly from a low cost scientific space mission. Such a raised profile will help achieve an increased interest in space activities and pave the way for future similar projects.