Merlion L & S Band System

Tai Wei Chua, Chee Teck Phua,
A/P Soon Hie Tan, A/P K Arichandran, A/P Choi Look Law
Satellite Engineering Programme
School of Electrical & Electronic Engineering
Nanyang Technological University
Nanyang Avenue
Singapore 639 798
Republic of Singapore
Telephone: 65 790 6148 Fax: 65 792 0415
Email: etwchua@ntu.edu.sg

James Wilhelm,
Alex da Silva Curiel, Zeno Wahl
Surrey Satellite Technology Limited
Surrey Space Centre
University of Surrey
Guildford
Surrey GU2 5XH
United Kingdom
Telephone: 44 1483 259 278 Fax: 44 1483 259 503
Email: j.wilhelm@ee.surrey.ac.uk

Session Topic: New Hardware in Space

Abstract. Under the MERLION project name, Nanyang Technological University of Singapore has teamed up with Surrey Satellite Technology Ltd. of the UK and developed a sophisticated communication payload on the UoSAT-12 mini-satellite which was launched recently.

The MERLION payload combines an analogue and digital regenerative transponder, with L-band uplink and S-band downlink. The transponder can be configured in-orbit for a variety of functions and experiments, and carries dual signal processors.

The digital uplink comprises a frequency agile L-band receiver, and 9600bps FSK and 1Mbps BPSK demodulators. The frequency agile digital S-band downlink is intended for high speed data transfer and will be employed to perform a variety of communication experiments. It is also capable of low bit rate spread spectrum communications, together with convolutional coding options to investigate its performance in the highly dynamic environment of LEO. The downlink can be configured to perform link characterisation at these frequencies. In conjunction with the 80386EX based On-Board-Computers, the digital uplink and downlink system can be configured into a high rate Store-and-Forward transponder.

This paper would introduce the basic Merlion architecture and design considerations, to realise the above functionality within the scope of a low cost mission.

Introduction

April 21, 1999, 11 am Baikonur Time. NTU's first satellite payload blasted into space, as part of the UoSAT-12 satellite.

The launch site was the Baikonur Cosmodrome, Kazakhstan. This is one of the key heavy launch facility of the Russian Space Agency. Sputnik (first artifical satellite) and Yuri Gagarin (first man in space) were both launched from this site.

The launch vehicle is a new rocket, known as Dnepr. This rocket, is converted from the SS-18 Inter-continental Ballistic Missile. The SS-18, the largest of the former Soviet Union's ICBM arsenal, has been targeted for decommissioning as part of the Strategic Arms Reduction Treaty. A small number of these launchers, will be converted into commercial launch vehicles.

The new payload, Merlion, is a highly flexible L/S band transponder, supporting various in-orbit re-configurable options. This paper would present more information about the Merlion transponder.

UoSAT-12 Mini-satellite

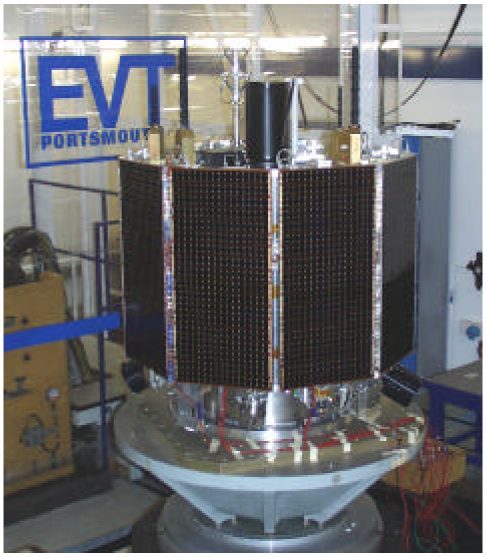

Figure 1 UoSAT-12 Undergoing Vibration Test

UoSAT-12 is the first of the new generation of mini-satellite class of satellites from Surrey Satellite Technologies Limited (SSTL) of the University of Surrey. This satellite is a 3-axis stabilized satellite, weighing over 300 kg, and represents a significant enhancement to the existing 50 kg, spin stabilized, gravity gradient micro-satellites manufactured by the company.

The satellite has been launched into a 65° inclined orbit at an altitude of 650 km. This orbit should provide the satellite with approximately 75 to 150W of electrical power, depending on the season.

The satellite is equipped with advanced Attitude Determination and Control Systems, including GPS, Star cameras, Horizon and Sun Sensors. In addition, this satellite is equipped with a variety of propulsion systems, including cold gas thrusters and resistojets.

For on-board data handling, two Intel 80386EX based processors with 128 MB of RAM each and one Intel 80186 processor is available. In addition, transputers are available to support the Earth Imaging Systems and DSPs to support the communication systems.

Merlion

The Merlion project started in 1996. Phase I of the project saw the installation of a satellite tracking facility in NTU. In the same year, engineers from NTU were attached to SSTL, a leading small satellite company in the UK. After three years of development, the UoSAT-12 satellite, with Merlion, is now safely in orbit.

Figure 2 NTU Ground Station

Traditional communication satellites operate from the GEO-stationary Orbit (GEO). Satellites in these orbits would remain stationary in space relative to the ground terminal, allowing one satellite to serve the needs of the ground terminals. GEO satellites are located about 36 000 km from the Earth. This huge distance would require significant uplink power for the ground terminal to be heard by the satellite. This large transmission power would make it difficult to realise small terminals with adequate power to access the satellite.

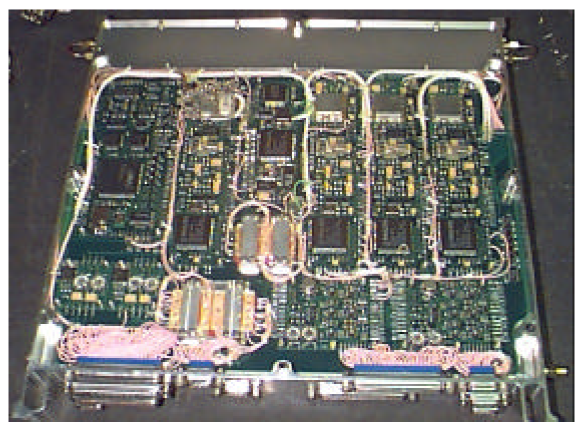

Figure 3 Merlion RF Module Tray

In recent years, a number of Low Earth Orbit constellations have been launched. It would be useful for future missions to be able to characterise the link parameters of a LEO environment. This however has not been easy and quite often GEO satellites and aircraft have been used to approximate the LEO satellite environment. The best way to investigate the LEO channel would be to launch an experimental/re-configurable communication payload into a Low Earth Orbit, and conduct experiments that would allow evaluation of coding and modulation schemes for optimum data throughput for a variety of satellite to ground station scenarios. Merlion would provide us this capability.

The Merlion transponder is capable of operating in both regenerative and clear channel modes. This would support the emulation of both the Iridium and Globalstar type of systems.

On board receivers and signal processors, together with re-configurable modulators add further flexibility to the system.

Possible Modes of Merlion Operation

Since 1998, the following major LEO satellite constellations have been launched:

1. Iridium
2. GlobalStar
3. Orbocomm

Iridium and Orbocomm are regenerative systems and GlobalStar is a bent-pipe system.

The Merlion system incorporates both regenerative and bent-pipe capabilities and would be well placed to allow evaluation of the performance issues related to these systems.

Regenerative

The regenerative system would use the DSP or OBC as the data source to drive the downlink modulator. By itself, the modulator would be able to support convolutional coding and direct sequence spread spectrum.

This modulator supports variable bit rates in order to support communications with handheld terminals. The downlink bit rate can be reduced by over 30 dB, improving the link margin by 30 dB at a reduced bit rate.

In order to investigate performance enhancement from different modulation schemes, the modulator supports BPSK, QPSK, OQPSK and MSK directly. In addition, the DSP module can be used to synthesise other types of modulation or coding schemes at low bit rates (up to a base band bandwidth of about 20 kHz).

For up link experiments, the DSP has direct access to a user-defined base band of 15 kHz in the L-Band (centred on 1.265 Ghz).

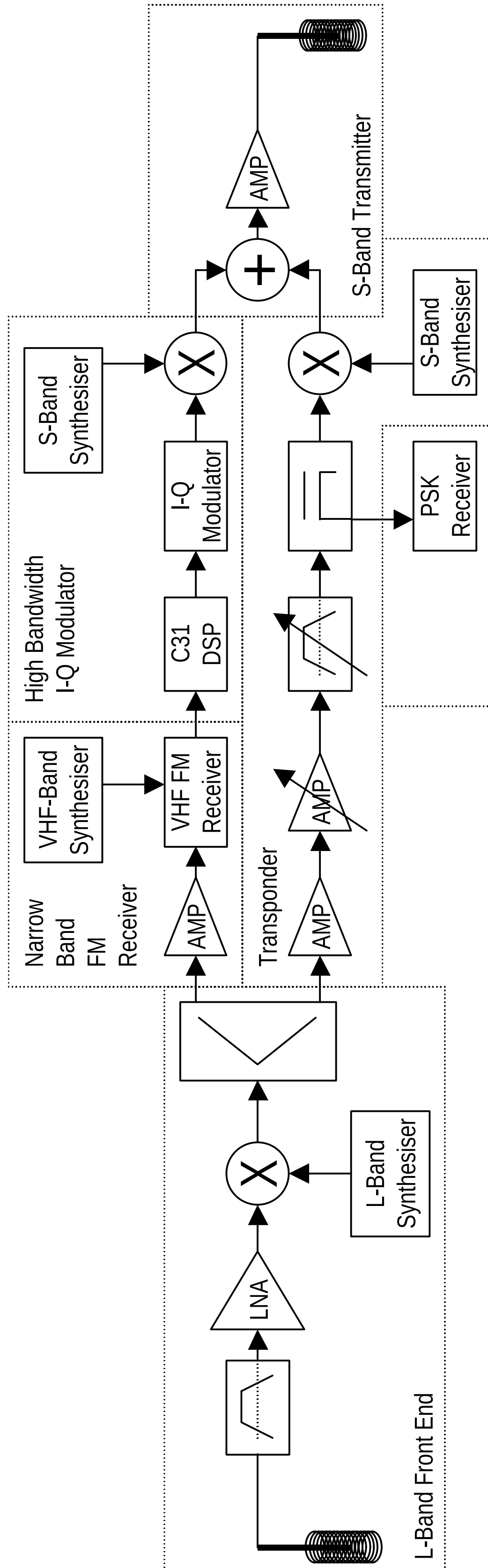

Figure 4 Merlion System Overview

Transponder

For schemes requiring additional resources not available on the satellite, the 1.8 MHz clear linear transponder would allow us to investigate any type of coding or modulation scheme that would fit within a 1.8 MHz bandwidth.

Experiments involving multi-user interference and other high bit rate or composite bit rate applications are being planned.

Antenna Pattern and Free Space Loss

The free space loss is a function of distance between the transmitter and the receiver.

For LEO satellite at an orbit-height of 650 km, the Free Space Loss (FSL) for an overhead pass at the horizon, with range of 2951962.40m, is 169.50 dB at S-Band and 163.84dB at L-Band. When overhead, the range drops to 650 km, the FSL at S-Band is now 156.36 dB and at L-Band, it is 150.71 dB. This reduction in free space loss, as compared to a GEO satellite, with the associated reduction in Equivalent Isotropic Radiated Power (EIRP) requirement for the mobile terminal, would make cellular satellite telephones a reality.

The FSL would vary by just over 13 dB. For a communication system, this would mean that the equipment would have 20 times more power when the satellite is overhead as compared to the case when the satellite is just above the horizon. If a constant bit rate link is to be maintained, the satellite would be in position to send more data when overhead as compared to the minimum bit rate chosen to operate at the horizon.

It is possible to redistribute the antenna gain to reduce the effects of this large variation in gain distribution. The Merlion payload would use an antenna with the following gain pattern:

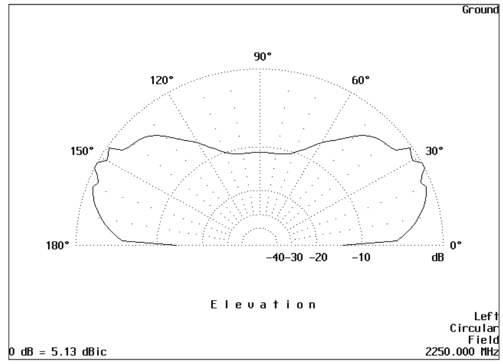

Figure 5 Merlion Shaped beam antenna

The following diagram shows the path loss variation without the antenna compensation and the result of using the above shaped beam to reduce the path loss variation.

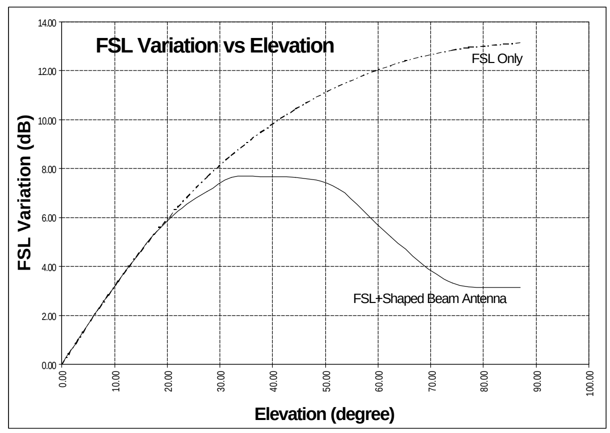

Figure 6 Free Space Loss and Antenna Shaped Beam Path Loss Compensation

As shown above, the antenna was able to reduce the link variation by over 5 dB. The effects start to show up above 20 degrees elevation.

The satellite does not occupy the same amount of time for all elevations. The following shows the distribution of time, above the horizon, that the satellite stays over a particular elevation. The information is derived by accumulating results from simulated passes over Singapore for a satellite at an orbital height of 650 km and at an inclination of 65 degrees, for a period of 10 000 orbits. The results are assigned to 90 bins from 1 degree to 90 degrees elevation.

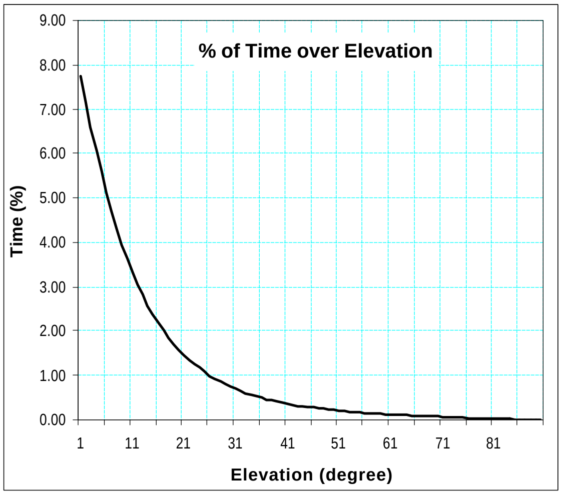

Figure 7 Proportion of Time vs Elevation

In order to get to a higher elevation, a satellite must pass through the lower elevations. Depending on the particular orbit, the satellite may not reach the maximum elevation for a particular ground terminal. As such, a major proportion of the time is spent at the lower elevations. The cumulative distribution of the Elevation Time is as follows:

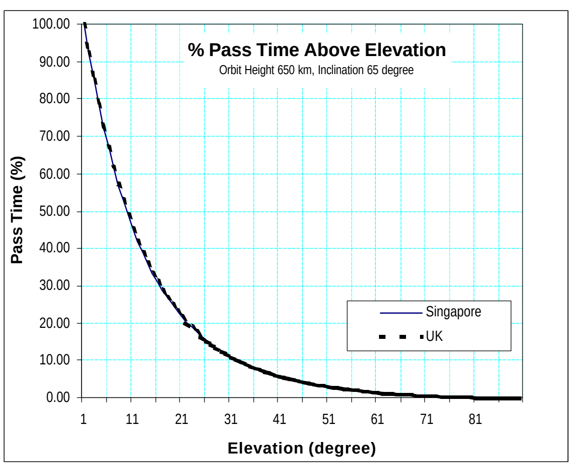

Figure 8 Cumulative Distribution of Elevation Time

The plot below shows the percentage of visible time, the satellite is above a particular elevation. If a ground terminal supports operation only above 10 degrees, it would lose over 50% of the pass time. As such, if maximum access time is desired, support for low elevation is very important. Elevations above 31 degrees occupy only 10% of the available pass time. The maximum antenna gain is available between 20 and 50 degrees or from the above diagram, about 18% of the available pass time.

The UoSAT-12 orbit is not Sun synchronous. As such, the ground track is not very symmetrical and is subject to seasonal patches whereby the satellite maybe more frequently observed by ground stations at different latitudes.

Depending on the priorities in the system design, there is much scope to experiment with various configurations. For example, if priority is for maximum data throughput, we would operate a variable rate modulation scheme, mapped to follow the available link budget. However, if the priority is for a simple low-power ground terminal, we may wish to constraint operation to the higher link margin parts of the pass.

System Design Issues

Power Amplifer Protection

The Merlion output amplifiers are linear amplifiers. As such, a strong ground signal within its pass band would drive it to saturation and beyond. A power sensor on the output of the amplifier detects excessive power output and takes corrective action.

This corrective action comprises of a timed command sequence:

1. The Transponder AGC gain is commanded down;

2. If after a command station defined interval, the output power is not reduced, the Up Converter is disabled;

3. Following this after a command station defined interval, the output power is not reduced, the power amplifier is taken off line;

4. Following a command station defined interval, the output power is not reduced, power is removed from the entire S-Band section of the payload.

The above protection scheme is handled by two micro-controller working in conjunction with the satellite data processing system. Each of these schemes are backed up by a higher level scheme. As such, it would be quite unlikely for this protection mechanism to fail.

Frequency Synthesiser reference frequency

The phase noise performance of a frequency synthesiser is related to the multiplication factor (LOG_2N) from the reference frequency.

As such, for the higher frequency synthesisers, and in particular, the L and S-Band synthesisers, a higher reference frequency is desired. A 50 kHz reference is used for VHF synthesiser and 100 kHz references are used for the L and S-band synthesisers. In addition, the command station is also able to change these references to 250 kHz. Although a larger step reference would mean a bigger frequency step size.

A smaller reference is desirable for the VHF synthesiser to provide for smaller frequency step sizes in tuning the up link receiver.

Isolated Input/Output connections

As part of the UoSAT-12 design philosophy, all the off-module connection from the various modules are isolated. These would remove ground loop issues. In particular, earlier experience has shown that leakage current from inter-connected modules was causing difficulties to completely reset digital logic.

For digital signals, the HP HCPL-0201 optical isolator was used. This part, although specified for operation to 5 Mbits/s has been shown to be usable up to approximately 1~2 Mbits/s, when external timing delays are taken into consideration.

For analogue signals, the Siemens ILQ74OPT9 was used. It was found that to achieve adequate linearity, we would need to bias the quiescent current to approximately 5 mA.

For power supply interfaces, Interpoint DC-DC regulators were used.

TCXO and Low Bit Rate Operation

The Merlion payload incorporated a High Power Amplifier (HPA) module. This HPA module is capable of raising the module temperature by over 30 degrees above ambient within 15 minutes of operation. A total of 4 frequency synthesisers are incorporated within the same module. These synthesisers take reference from independent on-board oscillators. Crystal oscillators are inherently sensitive to temperature drifts. Of these synthesisers, the L and S band synthesisers are particularly sensitive to temperature fluctuations due to its high frequency multiplication factor (240 for S-band).

Demodulation schemes, which are based on phase modulation, would typically be able to track a frequency drift of approximately 0.1 symbol rate. Without temperature compensation, the S-Band LO has been observed to drift by several kilohertz over the operating temperature range. This would limit our phase modulation to signals above 20 kHz.

In order to extend the operating range of the modulator, Temperature Compensated Crystal Oscillators (TCXOs) were used on one set of module trays. The redundant back up set was equipped with a software solution to trim the operating frequency using a VCXO. This approach is to hedge our bet using the proven (from earlier UoSAT missions) VCXO approach as compared to the unproven TCXO component.

Analysis with the HP89441A analyser showed that short-term frequency stability with the TCXO supported operation down to less than 4800 bps, as compared with the VCXO option, which works down to approximately 64 kbps.

Direct Up Conversion

The Merlion S-Band modulator supports the generation of a wide variety of modulation schemes with a wide range of bit rates. This modulator uses direct up conversion to I-Q modulate a quadrature mixer. The output of this mixer goes to the power amplifier stage and out to the antenna.

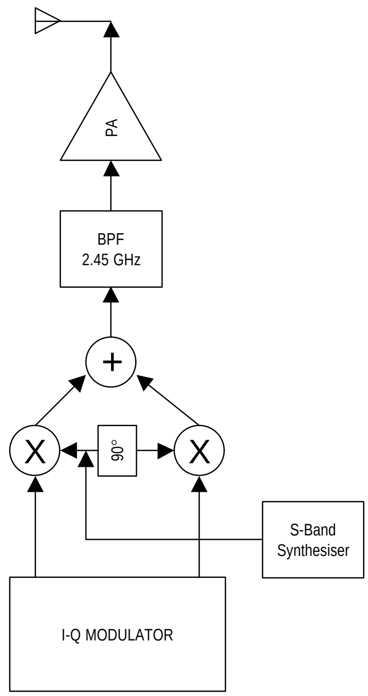

Figure 9 Direct Up Conversion IQ Modulator

This arrangement worked fine on the bench using bench synthesisers. However, during initial integration testing, once the above modules have been integrated into the compact Merlion module tray, it was found that the system no longer works. After a series of testing, it was concluded that the raw RF power from the power amplifier was leaking back into the Local Oscillators (LO) source and phase modulating it.

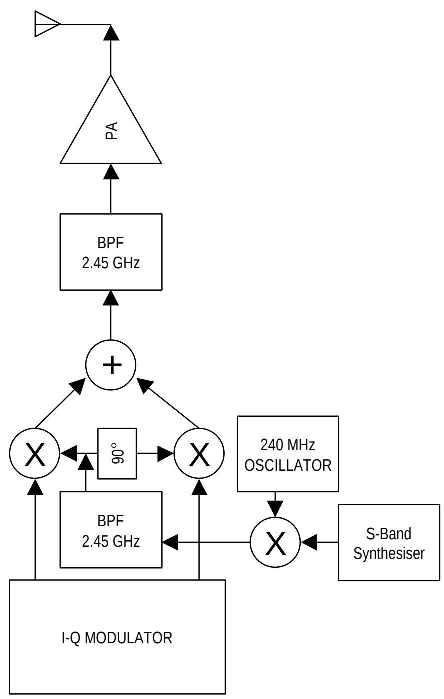

Figure 10 Modified Direct Up Conversion IQ Modulator

The solution to the above problem would be to move the phase modulated output away from the operating frequency of the LO. This was done by using a mixer to add in a 240 MHz offset into the S-Band (2.4 GHz) LO source. The S-Band LO is set to operate 240 MHz down from its initial setting, to keep the output at the targeted frequency.

This solution allowed us to implement direct up conversion into a high power amplifier without the need for a high linearity mixer, which is common with traditional dual conversion modulation. More importantly, the above change could be accomplished within the available space in the compact module tray.

Current Status of Merlion

Merlion is currently undergoing commissioning tests. This process is expected to take several months, due to the complexity of the system.

Subsequently, the payload would be available for open access, subject to the usual consideration of power budget, system maintenance, operational requirements and our research commitments.

Conclusion & The Future

This project is a collaborative effort between Surrey Space Centre (SSC), UK, and the Nanyang Technological University (NTU), Singapore. The project introduces the development team to new issues related to microwave communication systems, in particular, the need to pack components into small structures and still maintain adequate isolation for proper operation. The experience gained would be invaluable in our future missions to move from the crowded VHF/UHF band to the higher frequencies.

Acknowledgement

The authors would like to thank the National Science and Technology Board (Singapore), the Nanyang Technological University (Singapore), Surrey Space Center (UK), for the financial and technical support to make this project possible.

References

1. R.A. da Silva Curiel, E.S.Seumahu, S.H.Tan, T.W.Chua, "The UoSAT-12 Merlion Payload", Proceedings of AMSAT 1996 Colloquium, Surrey, UK, 1996.

2. R.A. da Silva Curiel, T.W.Chua, J.Wilhelm, "The UoSAT-12 Merlion regenerative communications transponder", 21st International Symposium on Space Technology and Science, Sonic City, Omiya, Japan, May 24-31, 1998.