The GANDER Microsatellite Radar Altimeter Constellation for Global Sea State Monitoring

Yuanxing Zheng
Surrey Space Centre, University of Surrey, Guildford GU2 5XH
Email: Y.Zheng@ee.surrey.ac.uk http://www.sstl.co.uk
Tel/Fax: +44-1483-259278/259503

Abstract: *In the last two decades satellite borne radar altimetry has been demonstrated as a very effective and accurate remote sensing method in sea state monitoring by over ten missions. Although all the previous missions have focused on oceanography, glaciology and land topography study, radar altimeter's unique advantage in providing fast access altimetry measurement of significant wave height (SWH) and sea surface wind speed sensing has also generated great interests in several commercial applications such as a constellation for global real time sea safety monitoring and the shipping route management.*

*In this paper, a low cost 12 microsatellite network called GANDER constellation (**G**lobal **A**ltimeter Network **D**esigned to **E**valuate **R**isk), jointly proposed by Surrey Space Centre (SSC) and Satellite Observations System (SOS), is presented. The paper first gives an outline of the radar altimeter's operational principle and main applications, then it focuses on a thorough feasibility analysis to demonstrate the microsatellite capability in this project, payload requirements as well as several most critical platform subsystems will be studied in detail. In the end, the 12 microsatellite constellations arrangement, which aims to provide world wide users of near real time access will be defined.*

This 12 small satellite system, as a much cheaper and more effective alternative for the conventional 'big' multi-sensors spacecraft, will allow a much faster and more frequent update for the global sea state change monitoring. Its appearance well presents the small satellite research and application trend – cheaper by the dozens, and faster by smaller.

Introduction

On this planet, over 70% of the Earth surface is covered by ocean, each year the marine insurance pays out nearly $2.6 billion as a result of bad weather. So there is always a great demand for monitoring global sea states, from locating ocean fronts, eddies and swells to providing real or near real time sea surface wave height and wind speed. In the past twenty years, several instruments have been developed to fit these requirements, among them radar altimetetry has been demonstrated as one of the most effective and accurate series in sea state monitoring.

The altimeter operation principle is conceptually simple: a nadir looking, high-resolution radar that measure the distance from the satellite to the ocean's surface with high accuracy. According to the radar signals reflection nature, the two-way travel time and hence the range to mean sea level, can be obtained by tracking the half-power point on the return waveform. The significant wave height (SWH) can be determined from the slope of the leading edge of the waveform in the vicinity of the half-power point, while the near surface wind speed is decided by the trailing edge of the return waveform.

SWH is a very useful tool in monitoring sea surface state. It corresponds approximately to the crest-to-trough wave height of the 1/3 largest waves in the altimeter footprint [1]. Its value may ranges from 1 to 20 meters. The altimeter return signal waveform is briefly shown in Figure 1.

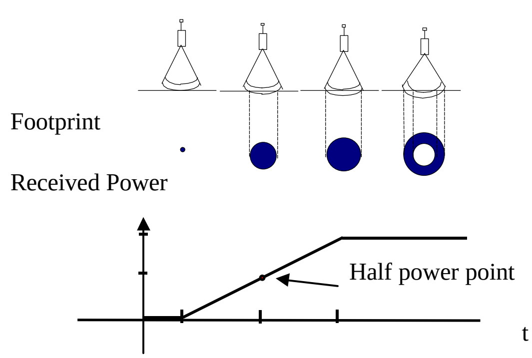


Figure 1. Radar altimeter return waveform

The applications of satellite borne radar altimeter can be grouped into two types: long-term and short-term measurements. A long-term history of altimetry data provides a profile of sea surface topography along the satellite track, these profiles are the fundamental information for oceanography as well as glaciology and land topography study. On the other side, the short term fast delivery altimetry SWH and sea surface wind speed sensing data have played important roles in commercial sea state alarm service such as sea safety consideration and the shipping route management.

The feedback from a range of end-users indicate that although a single satellite may deliver extremely useful information, the coverage falls far short of what is needed to provide a commercial, operational service. This leads to the concept of GANDER (**G**lobal **A**ltimeter Network **D**esigned to **E**valuate **R**isk) constellation, whose purpose is to monitor the oceans and warn shipping and other marine users of extreme wave conditions for real or near real time by a cheaper but more effective network.

Traditionally, radar altimeters have been very rarely launched as the main & single satellite payload. They usually were integrated and launched together with other remote sensing payloads such as SAR and radiometer. These missions include SEASAT, ERS-1/2, and TOPEX etc.. The main reason for this is that for sea surface topography study the altimeter range measurement accuracy must be controlled to cm level. While this target can not be achieved without the help from other on-board instruments. However, the interface with other instruments will not be necessary if only SWH and wind speed are the main concerns, as the altimeter itself can achieve these aims with reasonable resolution. This merit enables small satellite to become the possible platform candidate for the GANDER project. Furthermore, the improvement of altimeter design technique in the last two decades has reduced down the payload transmitter power requirement from several kW to less than 10 Watts, this improves the feasibility of using small satellite platform in great deal.

The GANDER constellation will employ 12 lower than 150kg microsatellites to comprise a global network to measure sea state directly from space and deliver reliable, timely information to enable the most damaging storms to be avoided. It is believed this network, as a much cheaper but more effective alternative for the conventional multi-sensors ‘big’ satellite, will make a major contribution to safety at sea, and has the potential to provide the basis for key advances in meteorological operations.

II. Microsatellite Platform

Surrey Satellite Technology Limited (SSTL), within The Surrey Space Centre, has pioneered the design and operation of modern microsatellites for a wide range of applications in the last twenty years. By April 1999, fourteen microsatellites and one minisatellite have been launched, and a further four microsatellites are currently planned for launch in 1999 through to 2000. The satellite family ranges from a 325kg ‘UoSAT-12’ minisatellite, to a 5kg nano-satellite ‘SNAP’, and to the ‘EarthRise’ and Lunarsat lunar missions, as well as several microsatellite constellations – such as the ESAT enhanced microsatellite project which targets hard-to-locate utility meters.

All SSTL platforms are derived from a modular microsatellite bus, Microbus-70, and larger platforms benefit from the flight heritage of the microsatellite platform. The enhanced Microbus-130 platform extends the available volume and particularly orbit-average power for more demanding microsatellite missions. The 320 kg Minibus platform offers the next level of payload services, and makes available greater volumes for payloads. The choice of platform is directly driven by the constellation cost as the increasing of the platform size not only increases the whole system cost, but also increases the launch fee. Figure 2 is a estimation for the whole constellation cost for different satellite platform buses.

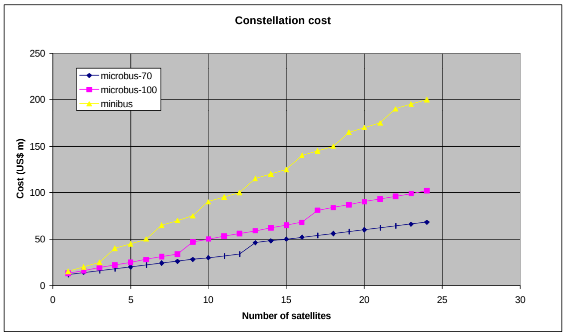


Figure 2. Cost of the constellation space segment

To choose which platform bus is primarily decided by the payload requirements on different satellite subsystems performance, such as attitude control, on-board DC power supply. Although the more powerful minisatellite platform can satisfy the altimeter payload requirement better compares with the microsatellite, due to the cost consideration shown in Figure 2, it will not be the first choice for the project. The characteristics of the two most likely GANDER altimeter platforms, MicroBus-70 and MicroBus-130 are briefly listed in Table 1.

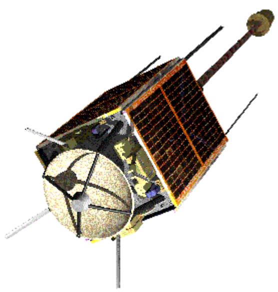
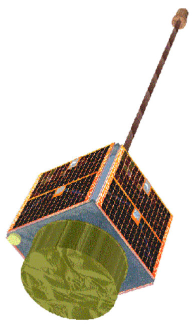
Platform	Characteristics	Application to GANDER
MicroBus-70 	Dimensions: 350X350X650mm Mass: 40-70kg Raw bus power 21-43W Processor 80C186 / 80386EX Data storage 256Mbytes TM/TC Central/distributed 9.6k-76.8kbps VHF/UHF Power system Centralised, 12V ACS Spin, (3-axis), 0.5° Navigation GPS or NORAD Options Station keeping Cold gas	Advantages • Low cost • High packing density for constellation launch Disadvantages • Limited solar power collection area • Limited scope for high antenna gain • Might not be able to fit payload
MicroBus-200 	Dimensions: 600X600X800mm Mass: 60-100kg Raw bus power 42-86W Processor 80C186 / 80386EX Data storage 256Mbytes TM/TC Central/distributed 9.6kbps-1Mbps VHF/UHF/S-band Power system Centralised, 12V ACS Spin, (3-axis), 0.5° Navigation GPS or NORAD Options Station keeping Cold gas	Advantages • Low cost • High packing density for constellation launch Disadvantages • Limited solar power collection area • Limited scope for high antenna gain • More costly

Table 1. Surrey Microsatellite Bus Characters.

.

III. Platform Subsystems Analysis

There are several critical platform subsystems, such as ADCS, DC power supply, communication link, may directly influence the whole system feasibility. It is, therefore, of great importance to have a precise understanding on each of them.

Attitude Determination and Control Subsystem (ADCS)

As radar altimeter is a nadir looking instrument, attitude determination and control system (ADCS) is one of the most crucial parts that may affect the altimetry measurement accuracy greatly. The attitude pointing errors effects can be divided into the following two parts.

The vertical component of satellite velocity relative to the sea surface introduces a Doppler shift in the frequency of the return signal received by the altimeter, and therefore introduces an error in the altimeter range estimation. For the radar chirp signal with sweep rate of *Q=3.125 kz/ns*, it corresponds to a Doppler shift range error of 13cm for a vertical relative velocity of *30 m/s* (maximum). This error is similar in nature to the EM bias in that the return waveform is shifted in frequency but otherwise unchanged in shape and therefore introduces an undetectable range error. As it does not influence the SWH estimation which relates to the returned waveform shape, and the Doppler range error can only be corrected on ground post processing, it will be omitted it in the on-board processing. Lower than 10 cm range error is acceptable by the customers anyway.

The pitch and roll error will result in an on-board antenna pointing error away from nadir, which has a serious impact on the altimeter measurement. There are basically two sources of mis-pointing errors: a static component which must be traded off between the various distortion of the satellite, and a time varying component associated with the thermal distortion of the satellite. The latter has a period that will decide the time constant of the smoothing filter in on-board tracking system. The typical value of ERS-1 is 0.2° static mispointing error and a maximum harmonic error of 0.1°.

It is only possible to keep the altimeter pointing normally to the ocean surface to within a certain accuracy; and the on-board estimates will be biased unless some correction is made for the "mispointing". For the well known altimeter return waveform model – Brown model [2], the existence of mispointing error x will mainly influence the flat surface impulse response of the radar altimeter return waveform, and therefore this response $P_{FS}(t)$ can be expressed as:

$$P_{FS}(t,x) \approx \frac{G_0^2\, l c s^0(0^0)}{4(4p)^2 L_p h^3} \cdot \exp\left[-\frac{4}{g}\sin^2 x - \frac{ct}{h}(\cos 2x + a)\right] \cdot I_0\left(\frac{4}{g}\sqrt{\frac{ct}{h}}\sin 2x\right) \quad (1)$$

here,

$t = t - 2h / c$ - time relative to the nadir pointing transmit time;

$\frac{4}{g} = (\ln 4) / \sin^2(q_w / 2)$

qw - usual antenna angular full width at half power

G0 - radar antenna boresight gain

l - radar wavelength

s0(0) - ocean's radar backscattering cross section at normal incidence

Lp - two way propagation path loss

The mispointing error can then give rise to the following three principle effects:

- A distortion of the leading edge of the average return, therefore a distortion in SWH estimation. In general, a pointing error will give rise to a decrease in slope of the leading edge of the return and this could be misinterpreted as a manifestation of surface roughness effects.
- Effectively reduce the level of backscattered power and, therefore, give rise to erroneously low values of s°, which is the base for near surface wind speed estimation.
- The third effect is when the pointing angle is larger than the on-board antenna half power angle, the trailing edge will have a increasing slope, this will lead to the tracking loss of the half power point.

The usual way in correcting the mispointing error is to apply a range window:

$$W(t,h) = \exp\left(-\frac{4ct}{hg}\cos 2h\right) I_0\left[(4/g)\sqrt{ct/h}\sin 2h\right]^{-1} \quad (2)$$

upon the received signal to correct the trailing edge of the real received signal $R(t,x)$ before the real estimation for SWH and backscatter coefficient. Here h is the estimated mispointing angle. The received signal $R(t,x)$, therefore, will become $R(t,x,h)$ as:

$$R(t,x,h) = R(t,x) \cdot W(t,h) \quad (3)$$

The corresponding waveform change is shown by Figure 3. It shows the weighting window flattens the trailing edge of the return waveform and drive the slope of the trailing edge to zero. When *x ¹ h*, the slope of this trailing edge will change with the different condition of x and h.

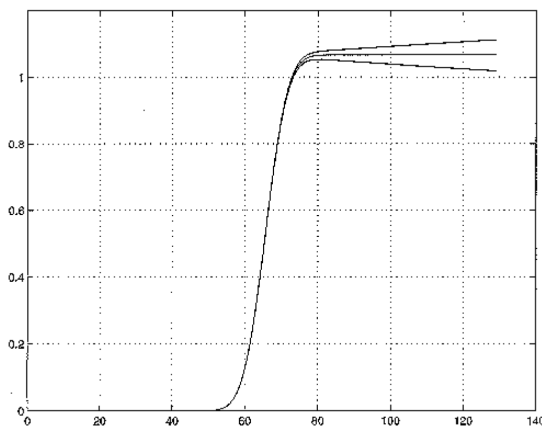


Figure 3. Different trailing edge slope at different x, h condition.

upper line – weighted waveform for x > h condition
middle line – weighted waveform for x = h condition
lower line – weighted waveform for x < h condition

Mathematics analysis shows the *R(t,x,h)* could be approximated as:

$$R(t,x,h) = L\left[1 + erf\,(t\ /\ s_c\sqrt{2})\right]\left\{1 + \left[(4/g)\sqrt{ct/h}\right]^2 (x^2 - h^2)\right\} \quad (4)$$

It then can be seen from the equation that the slope of the trailing edge of the return for large is governed by the difference $x^2 - h^2$. If $x > h$, the slope is positive, if $x < h$ the slope is negative. Thus the trailing edge slope may be used to update the current estimation of h. In the real application, a mispointing control loop is suggested which attempts to drive the trailing edge slope of the range window return to zero, the point where the estimated and actual values of the mispointing angle meet with each other. The mispointing tracking function is usually achieved by a traditional second order *a-b* filter, shown in Figure 4.

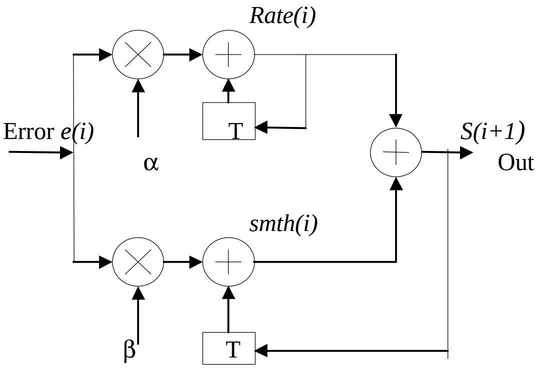


Figure 4. a-b filter diagram

The *a-b* filter is given in the form:

$$
\begin{aligned}
rate(i) &= rate(i-1) + be \\
smth(i) &= S(i) + ae \\
S(i+1) &= rate(i) + smth(i) \qquad (5)
\end{aligned}
$$

Here:
rate(i) : *i*-th signal rate,
smth(i): i-th smooth signal,
S(i+1) : (i+1)th estimated signal;
a, *b* : two constants, generally in altimeter they are set as *a=1/4*, and *b=1/64*;
e : the error signal.
T : is the loop constant, depends on system requirements. The larger the *T*, the more accurate the estimation, however the longer time for the loop to settle down. Generally speaking the filter update time depends on the altimeter PRF.

If assume the real-time altimetry output date is 10 Hz, then 100 ms is the smallest time period on which the signal processor interpret the waveforms. While for a typical UoSAT type microsatellite, the ADCS system will update its pointing estimation around every 20 seconds, which is very long time compares with the 100 ms.

Fortunately, notice from Figure 5, the off-pointing angle only change from 0.39° to 0.41° in 6 minutes. Therefore for this altimeter application, we could just use a constant mispointing value to weight the returned waveform during the 20 seconds ADCS update period.

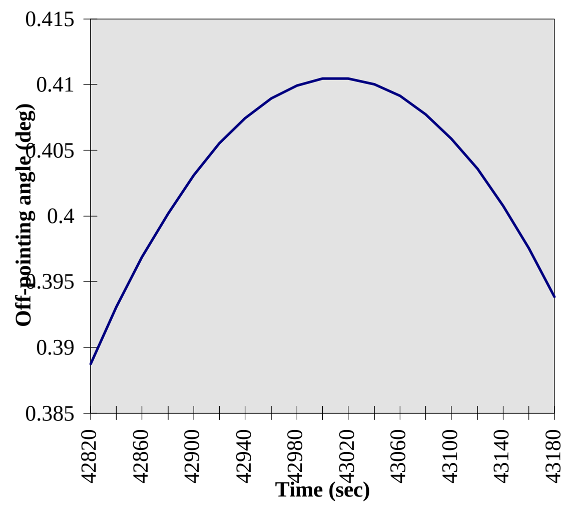


Figure 5 . UoSAT Microsatellite mispointing plot 360second period

Precise Orbit Determination

Precise orbit determination is a very important post-processing step in the conventional radar altimetry when high accuracy range measurement is required. From the early days of altimeter design, enormous work has been put in this area and several methods have been developed to accomplish that aim. For example, the TOPEX /POSEIDON altimeter, the most complex altimeter up to now, has four subsystems been implemented to precisely determine the orbit. They are:

- Satellite laser tracking (SLR) which is the nominal system for altimeter orbit determination computations
- Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS) tracking
- Global Positioning System (GPS) tracking
- Tracking and Data Relay Satellite System (TDRSS) tracking

For a microsatellite, it is obviously impossible to implement all the above subsystems on board. Fortunately the main task for this mission is different from the previous ones – only the satellite relative height above sea surface and the related radar return waveform are the main concern. Therefore the height of the satellite to marine geoid is not very critical to the project, at least currently.

However the altimeter payload does need the reasonable accurate orbit information to format the output telemetry data for world wide users to locate the altimetry results. The role will be played by the microsatellite on board GPS receiver which currently can provide an accuracy of up to 10 ms. It is believed this resolution can satisfy enough of the user requirements on commercial applications.

Station Keeping

For any network constellation, station keeping is always a very crucial question. It appears to be extremely significant to microsatellite due to its mass and volume restriction. Fuel propulsion budget and therefore the tank size must be evaluated carefully to decrease the platform price.

Atmosphere drag, geomagnetic force and solar pressure are the main influence to the stability of station-keeping. Among them the requirements are dominated by orbital aerodynamic drag. Differential in-track corrections between two adjacent satellites are negligible compared to this. Cross track errors are small and can be tolerated in the mission, simplifying the thruster arrangement to a simple in track system. The acceleration of the spacecraft caused by its interaction with the Earth's atmosphere can be described using the following equation:

$$\overline{F}_D = -\frac{1}{2} C_D \frac{A}{m} r(h) V_r \overline{V}_r \qquad (6)$$

where

CD : satellite drag coefficient, typical values ranges from 2 - 2.5

$\overline{V}_r$: satellite velocity relative to the atmosphere

ρ(h) : atmospheric density at the altitude h;

m : satellite mass;

A : satellite cross-sectional area projected normal to $\overline{V}_r$;

To overcome this drag force, energy is required. The ΔV budget is traditionally used to account for this energy. Shown from the above equation, the drag force changes with different satellite altitude as the atmospheric density is different. Figure 6 shows this relationship [5].

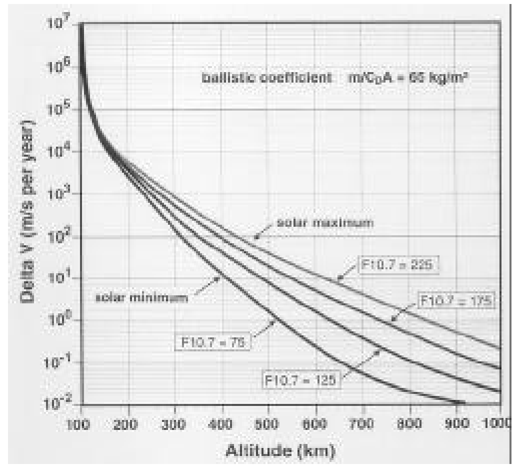


Figure 6. Satellite altitude vs. DV

Although shows from the above figure, the higher the altitude, the less the *DV* is required, due to the propagation attenuation, the higher the altitude, the larger the transmitted power is required. Therefore there is always a trade-off for the system design. At 800km altitude, assuming conditions near solar maximum, a delta-vee of approximately 0.75 m/s per year is required.

An existing N_2 cold gas system design for the SSTL MicroBus is a good candidate for station keeping [6], it could employ up to 600 bar tanks in a 330x330x200 mm^3 volume. The system configuration is illustrated in Figure 7. For a 100 kg spacecraft, the system offers a delta-vee of approximately 16m/s, using a 0.01 N thruster. A delta-vee budget of 10 m/s would permit a constellation deployment into their respective slots along the orbit within 3 months, leaving 6 m/s for more than 7 years of station keeping fuel. For the 50 kg microsatellite, less fuel maybe carried, as the general system design life is about 3 years.

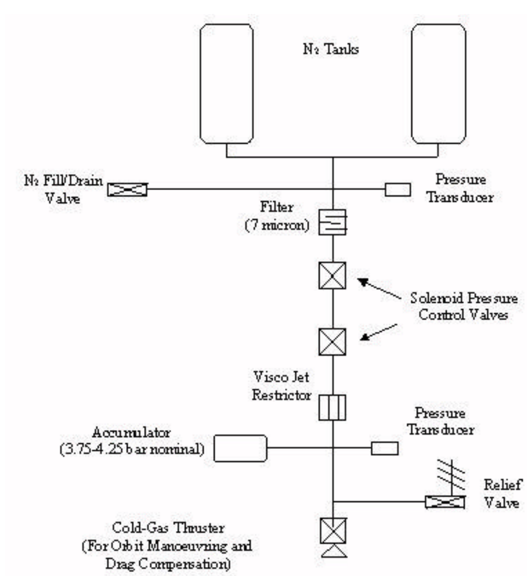


Figure 7. MicroBus cold gas station keeping system

Communication Link

The consideration for communication link can be divided into two sections. One is a low data rate real time broadcasting for world wide shipping users, the other is a relative high rate link for the scientific data transfer when satellite passes the main ground station.

For the real time data broadcast model, the communication capability requirement is very low, as stated in the previous section, a 10Hz altimeter output date is acceptable for most of the applications. The output frame includes the basic information of satellite orbit position, SWH, satellite height and wind speed information, the total date need to be down loaded for broadcasting is therefore around 200 bytes per second. Thus a very simple UHF link could achieve this task.

At the same time, it is also very important to have a high capacity down link so that when the satellite passes the main ground station the data recorded by the on board data recorder can be transferred. The data rate will be decided by the location and numbers of the main ground stations.

It is recommended that the high download link shares the same Ku band dish with the altimeter payload so that to decrease the transmitter power requirement.

Antenna

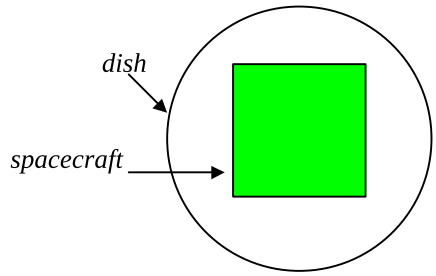
The importance of antenna lies not only in its gain may directly influence the received signal amplitude, but also in its size will effect satellite stability as well as launch feasibility greatly.

Generally speaking, dish is a common choice for high gain antenna at Ku band (13.6 GHz). The dish size of the previous altimeter missions vary from 0.6 meter to 1.5 meter, depends on system power budget. Considering the actual sizes of the two microsatellite platform indicated in Table 1, it is recommended that the antenna diameter be smaller than 1 meter. The calculated gain for Ku band 0.7 meter and 1 meter antenna therefore are:

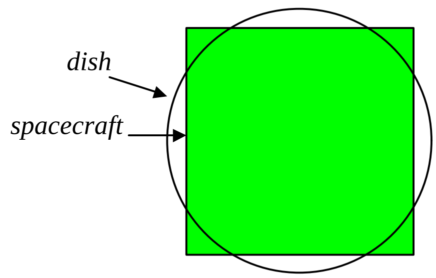
$$G = 17.8 + 20\log D\big|_{D=0.7} + 20\log f\,|_{f=13.6} = 37.5dB$$
$$G = 17.8 + 20\log D\big|_{D=1} + 20\log f\,|_{f=13.6} = 40.5dB \quad (7)$$

in the above equation, efficiency η = 0.55 is assumed in the calculation.

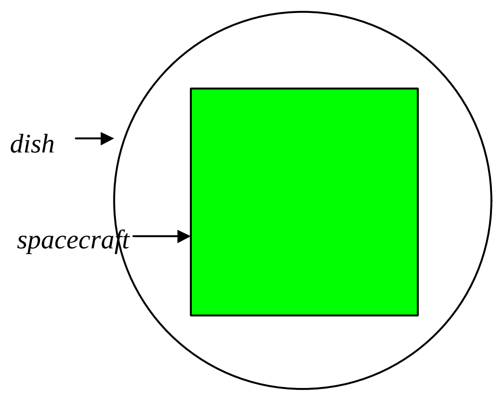
Diagrams in Figure 8 show three possible combinations of two different satellite platforms, MicroBus-70 and MicroBus-130, with two size of dishes, 0.7 meter and 1 meter diameter dish.



(a) MicroBus-70 with 700mm dish (ratio 1:20)



(b) MicroBus-130 with 700mm dish (ratio 1:20)



(c) MicroBus-130 with 1000mm dish (ratio: 1:20)

Figure 8. Bottom view of three combination of satellite platform and dish

If the antenna size is too large compared with the spacecraft, it may suffer from vibration difficulty in the launch stage. However it is very possible to design the antenna as a deployable type, although it may cost more.

Another thing need to note is the antenna size may also impose a restrict requirement on the satellite attitude control capability. It is known the larger the antenna, the smaller the antenna half power angle, and therefore the more restrict the requirement on satellite attitude control. For example, the half power angle of 0.7 meter antenna is 1.1°, while this drops to 0.75° for a 1 meter dish.

The previous altimeter missions experience has verified that the satellite pointing error must be kept smaller than the antenna's half power angle, otherwise the on-board tracking unit will lose the return waveform half power point track. From this point of view, the smaller antenna may have advantages over the larger one.

On-board Power

The DC power supply is always very critical to the satellite platform and payload design, especially for the power limited microsatellite platform. To understand how much average power the microsatellite bus can provide, a simulation had been done for Sun Synchronous orbit at two different attitudes The assumptions are:

- typical UoSAT microsatellite GaAs solar panel configuration
- 1 BCR Sun synchronous orbit with similar Hour Angle as UoSAT-5 (around 10:30 o'clock) Vernal Equinox day is chosen

The simulated orbit average DC power from solar panels are :

Satellite Orbit	Orbit Average Power (W)
h=800 km (MicroBus-130)	33.15
h = 700 km (MicroBus-70)	26.02
h = 1000 km (MicroBus-130)	27.37

Table 2. Simulated average DC power generation for different orbit

Consider the efficiency of battery charge/discharge, power converter etc., the possible available DC power will be around 20 Watts for MicroBus-70, and 25 Watts for MicroBus-130. Also considering the ocean area is approximately 70% of the total earth surface, we can then assume the average available DC power is roughly 28.5 W, and 36 W respectively.

Payload & Platform Power Budget

The single-pulse received SNR can be determined from the standard radar equation [3]:

$$\frac{S}{N} = \frac{P_t G A s t}{(4p)^2 kTN_F h^4} \qquad (8)$$

in here:

1. P_t is the peak transmitted power, assume 7 W for this project
2. G is the antenna gain, assumes a 0.7 m diameter Ku band parabolic antenna be used, the gain is $G = 17.8 + 20\log D\big|_{D=0.7} + 20\log f\,|_{f=13.6} = 37.5dB$ (η=0.55)
3. A is the antenna area $A = pR^2 = p(0.35)^2 = 0.38m^2$
4. s is the radar cross section of the illuminated surface, assumes the normalised cross section $s_0 = 6dB$, then $s = p \cdot c \cdot t \cdot h \cdot s_0$ $= pc \cdot 3.125 \times 10^{-9} \cdot 800 \times 10^3 \cdot 4 = 0.94 \times 10^7$
5. τ_0 is the transmitted pulse length, τ_0=100μs
6. k is the Boltzmann's constant, $k = 1.38 \times 10^{-23} J/K$
7. T is the antenna temperature, assumes *T=300K*
8. N is the receiver noise figure, assumes *N=5dB*
9. h is the satellite height, assume *h*=800km

The calculated SNR for one transmitted pulse is therefore:

$$\frac{S}{N} = \frac{P_t GAst}{(4p)^2 kTN_F h^4}$$
$$= 10\log\left(\frac{7 \times 0.38 \times 0.94 \times 10^7 \times 100 \times 10^{-6}}{(4p)^2 \times 1.38 \times 10^{-23} \times 300 \times \left(800 \times 10^3\right)^4}\right)$$
$$+ 37.5 - 5 = 12.2dB \qquad (9)$$

One thing needs to be pointed out, the above equation does not consider the system loss which in general is around 2-3 dB. The reason is this loss can be cancelled out by the processing gain via averaging a group of received waveforms. As we know the Rayleigh noise in the received signals decreases as the square root of the number of waveforms in the average which will give a roughly 3-4 dB gain. In this project we will average a group of 100 pulses before forming one output data format.

Using equation (9), a diagram shows the relationship between satellite altitude and transmitted power is plotted, shown in Figure 9. Here, all other parameters are the same as the values that set in the above calculation.

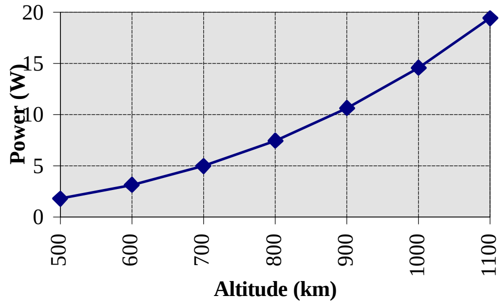


Figure 9. Satellite altitude vs. required transmitted power
(assume the received SNR is 12dB)

Although see from the plot, the lower the altitude, the less the transmit power required, consider the atmosphere drag on station keeping requirements shown in Figure 6, there is still a trade-off for the choice of suitable satellite orbit.

As 12 dB is an acceptable value for received SNR, the parameters in equation (9) will be used to calculate the platform and payload power budget. The whole radar altimeter payload includes

1) transmitter link – digital chirp signal generator, up conversion, power amplifier;
2) receiver link – low noise amplifier, deramping mixer, down conversion;
3) signal processing unit -- A/D, power spectral analyser, SMLE tracking processor and ***a-b*** filter.

Their power consumption can be summarised as:

- **Transmitted Link**: the transmitter link mainly contains chirp generator, up-converter and power amplifier.

1) Chirp generator – Qualcomm Q2368 130MHz Dual DDS (power = (15 mW/MHz)*(clock rate) = 1.95 W) and Harris HI5721 10 bit 125 MHZ DAC (power = 650 mW) are chosen for the chirp generator. The total power consumption is estimated around **3W**.

2) Up-conversion – The output signal from chirp generator is around 0dBm, according to the above diagram it will be mixed twice and multiplied six times before it finally be fed to the Ku band power amplifier. The efficiency of mixer and multiplier, however, will be very low, roughly around 10%. During this conversion link, some drive amplifiers will possibly be adopted. Fortunately all these operations are in small signal regions, so a allocation of **1W** will be enough for the whole up-conversion link.

3) Power amplifier – Power amplifier is the part that consumes most of the DC power when a chirp signal is transmitted. Generally speaking, the average efficiency of one stage amplifier plus power combiner is around 20%, if linear phase is required at the output. Also the higher the output power, the lower the efficiency we would expect. Therefore we can calculate the power requirement for 7W peak power output is 35W. Considering the duty cycle influence (10 SWH data frame per second, 100 signals average per data frame, 100 µs per pulse, then the total duty cycle is 10%), therefore the average power required is **3.5W**.

- **Receiver Link** – the receiver link's LNA does not need much power, in here we allocate **1W** for the total requirement.

- **Signal Processor** – After discussed with several people who has altimeter payload or simulator hardware design experience before, we believe **5W** DC power is purely enough for this mission by using the new generation powerful digital signal processor. The function of this signal processor covers:

a) Power spectral analyser – for this application each 128 points FFT shall be finished within 900 µs. DSP is an ideal choice, ADSP21020 or TSC21020E are recommended due to their radiation tolerant and powerful function.

b) Adaptive tracker unit (ATU) – The ATU can be implemented by a general 80186 microprocessor, or a programmable DSP.

c) Synchroniser/Acquisition/Calibrate Unit(SACU)

d) Spacecraft interface – This subsystem receives the engineering date and commands, and format the telemetry data, 1W is enough for a general use.

In summary for the whole system – microsatellite platform plus a medium resolution radar altimeter payload, the average DC power consumption budget is calculated, shown by Table 3.

System Components	Average DC Power (W)
Altimeter radar payload	13.5
Communication downlink	2.5
GPS	5
ADCS (one wheel)	3.5
OBC	4
Total	28.5

Table 3. System power budget

Refer to the available average DC power analysis above, we can see the MicroBus-70 can just meet the system requirements without much margin, while the MicroBus-130 will provide reasonable high margin.

GANDER Constellation Arrangement

As altimeter is a nadir looking instrument with very narrow antenna beamwidth, its swath width is consequently relatively narrow, calculated as:

$$Swathwidth = 2\sqrt{cth}$$
$$= 2\sqrt{3\times10^{8}\times3.125\times10^{-9}\times800\times10^{3}} = 1.732km \quad (10)$$

While according to the customer survey, the grid of the desirable global altimetry map should be less than 600 km. This requirement along with the global real time monitoring request impose a big challenge on the constellation arrangement.

The final 12 satellites arrangement are shown by Figure 10. All 12 satellites operate at sun synchronous orbit, and they are grouped into two. Each group of six satellites are equally distributed between two satellite continuous passes. The angle between satellite 6 and satellite 12 planes are 90 degrees.

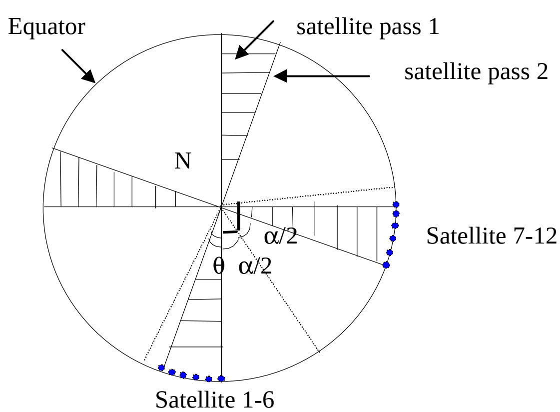


Figure 10. Constellation basic diagram

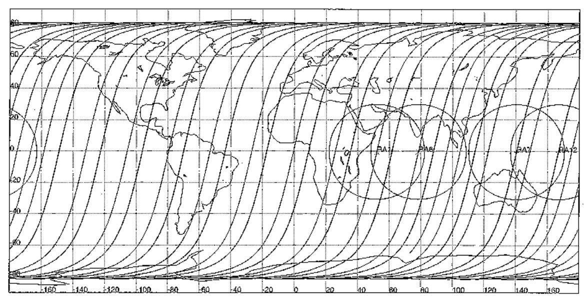
In the above diagram:

α/2 = 27.3°: the half angle of broadcast antenna
θ = 26.28° : the angle between satellite two continuous passes

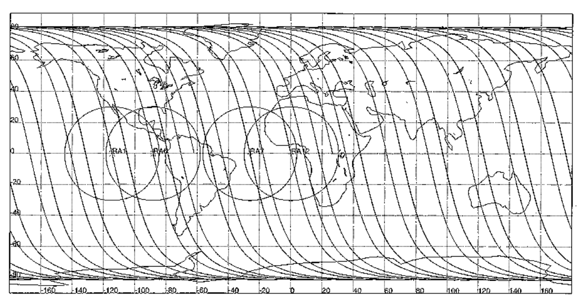
it is noticed:

$$q + a / 2 + a / 2 = 26.28^{\circ} + 54.6^{\circ} = 89.22^{\circ} \quad (11)$$

The above equation presents a very interesting result, as it tells us the angle between satellite No.1 and satellite No.7 is roughly 90 degree, that means if the constellation is arranged like that, all the satellites pass the same latitude simultaneously at different longitude, then there will have no scenes straps between the area illuminated by satellite No.6 and No.7, even near equator. Put in another way, each group of six satellites footprint can cover nearly half of the earth, and the coverage is seamless between the two groups. Figure 11 shows the satellites descending and ascending footprint. It can be seen that within one satellite period the footprint of the whole altimeters network could cover most area of the world. In here, in order to show clearly RA2 ~ RA5 & RA8 ~ RA11 passes are omitted. From the figure present clearly in descending part, the satellite footprint covers from longitude 20 ~ -160 degree, while in the ascending part the satellite network footprint covers from longitude -150 ~ 30 degree.



(a) Descending



(b) Ascending

Figure 10. 12 altimeters network footprint diagram within one satellite period

For this arrangement, when consider again the worst case – the ship is in equator area, and satellites 6 just pass the ship, then the ship only need to wait another satellite period (100 minutes for 800 km) before it appears in satellite 7's footprint area. As the each group of six satellites are equally distributed within satellite two continuous passes, while the distance *D* between this two passes are *D=3300 km* for 800 km attitude. Therefore the altimetry map grid is:

$$d = \frac{D}{(n-1)} = \frac{3300}{(6-1)} = 660km \quad (12)$$

where n is the satellite numbers.

It actually means for the worst case, when a ship is in equator and locates in the middle of the two satellites, the altimetry results it can receive is only 330km away.

The above simulation discussion show clearly that this 12 microsatellite constellation provides a relatively narrow altimetry map grid as well as a reasonable short user waiting time, which can satisfy most users requirements!

Conclusion

In this paper, a concept of 12 microsatellite low cost global real time sea state monitoring constellation is presented. The platform and payload design feasibility, as well as the network arrangement are investigated and analysed in detail. It is estimated that the whole system cost, platform and launch fee, is under 50 million USD, only a small fraction of the conventional 'big' multi-sensors satellite which usually is over several billion USD. This concept well represents the small satellite development trend – Cheaper by the dozen, and faster by smaller!

Reference

1. Chelton D.B., et al "Pulse compression and sea level tracking in satellite altimetry" Journal of atmospheric and oceanic technology vol. 6, 1989, pp. 407-428
2. Brown G. S. "The average impulse response of a rough surface and its application" IEEE Transaction on antenna and propagation pp.67-74, vol. AP-25 No.1, 1987
3. Marth P. C. et al, "Prelaunch Performance of the NASA altimeter for the TOPEX /POSEIDON Project," IEEE Transactions on Geoscience and remote sensing, pp. 315-331, vol. 31, 1993
4. Levrini G. et al. "The ERS-1 RA tracking algorithms" 10th Annual International Geoscience & Remote Sensing vol.3 pp. 2065-2068, Frascati, Italy, May 1990
5. Peter Fortescue, John Stark "Spacecraft System Engineering" John Wiley and Sons, 1995
6. J.Drum, T.Lawrence, "Results of initial feasibility study for a micro-satellite propulsion system", SSTL internal technical note