ALTIMETER DATA PROCESSING ON BOARD THE TOPEX SATELLITE

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ABSTRACT

The digital processing within the radar altimeter on board the TOPEX satellite to obtain science and engineering telemetry is described. The application of the Fourier transform, a second order tracking loop, waveform compression, and telemetry formatting is required.

INTRODUCTION

A radar altimeter is scheduled for flight August 1992 on board the TOPEX ocean topography experiment satellite. The digital processor within the altimeter performs all processing necessary to accomplish real time tracking of the ocean's surface and to derive selected oceanographic data. The two primary outputs of the processor are the precision height, from which the ocean geoid and surface topography are determined, and the ocean waveheight estimate. Altitude is measured with 2-cm precision using one second averaging. Ocean waveheight accuracy for once per second measurements is to within 10% or 50 cm, whichever is larger over a range of 1 to 20 meters. The altimeter is a dual frequency design that provides the capability of ionospheric disturbance correction. Altimeters have previously been flown on board earth orbiting satellites GEOS-3, SEASAT-A[1] and GEOSAT-A[2]. Along with the increasing precision and usefulness of the altimeters, the type and complexity of the data processing performed digitally has advanced markedly. This paper describes the digital processing necessary to accomplish radar return signal tracking and telemetry formatting on board the TOPEX satellite. Hardware implementation[3] is not addressed in this paper. The TOPEX altimeter has many modes of operation: for search and acquisition of the return signal, for calibration and test, and for error recovery. The focus will be on the high resolution track mode, and its data products.

THE PROCESSOR

Filter Bank

Digital signal processing starts at the input to the filter bank (Figure 1). Here the in phase and quadrature phase components of the receiver video output are analog to digital converted. The radar return pulse is 102.4 μsec wide dechirped video. The in phase and quadrature phase components are each digitized into 128 samples. The return contains frequencies that are the result of mixing, in the RF section of the altimeter, the return pulse with the linear chirp signal which generated the transmit pulse. Higher frequencies result from higher altitudes. The tracking error may be nulled by frequency shifting. Under control of the tracking loop, frequency is shifted by a small amount. Frequency shifting is accomplished by multiplying the samples, as they are digitized, by a rotating phaser. The phaser rotation rate is made proportional to the amount of frequency shift required. After frequency shifting a 128 point complex fast Fourier transform is performed, followed by squaring and summing the complex components of each spectral output point of the transform. The resulting series of spectral energy points is the radar return waveform for one transmitted pulse. In the high resolution track mode 228 Ku-band returns are averaged and 60 C-band returns are averaged in 50 msec before transfer to the tracking loop for further processing.

Tracking loop

A tracking loop is needed to keep the receive chirp pulses which deramp the chirp radar return coincident with the return signal. A height error is developed by examining the rising edge of the spectral energy waveform. In the high resolution track mode, an amplitude gate and six sets of early, middle, and late gates are formed by summing adjacent sample points along the waveform. From these sets of gates: the rise time of the leading edge of the return is determined, the optimum set of gates for tracking the height error is selected, and a value proportional to the mean ocean waveheight is computed. To determine height error the gain control gate is subtracted from the selected middle gate. This result is properly scaled to form a value proportional to the tracking loop misalignment. The height error drives a second order tracking loop which produces zero error for zero acceleration. A receiver gain control loop is also established. The height and height rate developed by the tracking loop, and the receiver gain is transferred to the synchronizer which must further processes this data and communicate results at the proper time to other functional units.

Burst Complete Handler

The burst complete handier is an interrupt initiated task. It contains the operating system that initiates the execution of all other tasks and synchronizes events which must be coordinated with a specific burst interval. These events include reading the spacecraft clock, and issuing the send-waveforms signal to the digital filter bank. At the end of each burst, the burst complete handler processes data needed by the synchronizer and sends it to the synchronizer. The burst interval is a function of the altitude of the TOPEX spacecraft. The planed mission calls for an altitude between 1,274 km and 1,394 km giving a burst interval of between 8.5 msec and 9.3 msec. The variable burst interval gives a variable telemetry rate. For this reason time tagging of each science telemetry frame is very important. Spacecraft time is used to tag the start time of each science telemetry frame. The total time tag error is within 10-μsec.

Closely associated with the burst complete handler is an error handler. The data processor contains two watchdog timers. Both are window timers which require a periodic reset or an error signal is generated. One watchdog timer is set to the burst rate. The other watchdog timer is set to the track rate. The data processor contains an error mode register which is loaded by ground command and accessible for read by the processor. The error mode register allows selected areas of read-write memory to be write protected. The error handler permits several types of recoveries from single event upsets.

Synchronizer

The synchronizer extrapolates the height for each transmitted and received pulse by adding the height rate. It separates the height into a starting time for the chirp generator and a frequency shift value for the digital filter bank. The synchronizer develops the timing sequence for transmit and receive control pulses for the RF section. The pulses are 102.4 μsec wide and separated by 5-μsec. Transmit and receive time slots alternate for each frequency. A C-band pulse return may be received while a Ku-band pulse is transmitted, and visa-versa. The series of pulses transmitted during the two way travel time to and from the ocean surface is called the burst sequence. A gap between bursts of a few hundred μsec with no transmit or receive pulse is maintained to accommodate height variations. The nominal burst interval corresponding to the TOPEX orbit 1334 km is 8,893 msec. During a burst interval 38 Ku-band pulses and 10 C-band pulses are transmitted and received.

Chirp Generator

The chirp generator produces a linear frequency sweep known as a chirp pulse. A linear frequency sweep is a parabolic progression in phase angle of a sine function. A parabola is generated by integrating a ramp function. For TOPEX the digital implementation of the liner frequency sweep is accomplished by driving a 14-bit counter at 80 MHZ to generate the ramp function. The counter output is accumulated to generate the parabolic function, and the eight most significant bits address sine and cosine memory to generate the frequency sweep. A pair of digital to analog converters pass the frequency sweep to the altimeter RF section. The frequency sweep generated is at baseband which requires both in phase (sine) and quadrature phase (cosine) outputs. The frequency sweep is from -20 MHZ to +20 MHZ. The sweep is multiplied up to a 360 MHZ bandwidth chirp pulse in the RF section for both Ku-band and C-band.

Waveform Compression

The waveforms, after use by the tracking loop, must be further averaged by accumulation down to 10/sec for Ku-band and 5/sec for C-band. Each averaged waveform is compressed by a factor of two, from 128 samples to 64 samples. The compression algorithm leaves unchanged the important rising edge of the waveform, but averages samples by four and then two before the rising edge and two, four and then eight after the rising edge. Finally a waveform must be scaled down to an eight bit magnitude for each of the 64 samples with a four bit scale factor.

Science Telemetry

After the waveforms are compressed they are written into the science telemetry buffer along with associated data such as height, height rate, ocean waveheight, and receiver gain. Interface to the spacecraft telemetry is accomplished with a single telemetry frame of buffer storage. Unloading the buffer into the spacecraft telemetry stream always takes slightly less time than filling it. By delaying the start of a telemetry frame transfer until the buffer is at least ½ full, unloading will never overtake filling. The telemetry format is designed so that data is written to the buffer in the order in which it is produced. This assures that data is always available for output to the spacecraft after a altimeter telemetry frame readout has been initiated. The last buffer entry is the checksum.

Science telemetry frames are produced at the rate of one frame per 20 track intervals or approximately once per second. Because of the variation in altitude the science telemetry rate varies between 9.6 kbit/s and 9.9 kbit/s. The fixed readout rate of the spacecraft allocated for the altimeter science telemetry is 11.6 kbit/s. The altimeter frames are read into the spacecraft data stream in a burst mode. The altimeter frame is synchronized with the spacecraft telemetry only at the 8-bit byte level. A 48-bit synchronization code is used to identify the start of a science telemetry frame in the spacecraft telemetry. Contiguous science telemetry frame bytes are read into the spacecraft telemetry. After the last altimeter frame byte is read, spacecraft telemetry bytes allocated to the altimeter are zero filled until the next altimeter frame is released starting with the synchronization code. Each science telemetry frame is time tagged with spacecraft time which was read within 1-μsec of the transmission of the first radar pulse of that frame.

Spacecraft Interface

The altimeter is assigned two distinct telemetry streams, a science telemetry stream described above, and an engineering telemetry stream. These streams are part of the overall spacecraft telemetry format. The spacecraft uses a basic time division multiplexing approach for its telemetry formatting. It divides an 8.192 second major frame interval into 128 minor frames. Each minor frame is 128 bytes. This results in a overall rate for the telemetry stream of 16 kbit/s. Ninety three of the 128 minor frame byte slots are allocated to the dual frequency altimetrer when the altimeter is in a operational mode. These slots are allocated to other instruments when the altimeter is not operational.

Engineering Telemetry

Temperatures, voltages, and currents included in the engineering telemetry are needed to calibrate and monitor the health and status of the instrument. The altimeter is fully redundant except for the antenna and passive microwave couplers. The decision of which redundant side of the altimeter to utilize can hinge on engineering telemetry.

One spacecraft minor frame slot is always allocated to the altimeter engineering telemetry stream allowing one byte of data to be read every 64 milliseconds. The altimeter synchronizes its engineering data readout to the spacecraft major telemetry frame. Therefore the altimeter engineering data format consists of 128 bytes that repeat every 8.192 seconds. The software process running the height tracking loop within the microcomputer is convenient for processing engineering telemetry. Since the tracking loop processing repeats at 50 msec intervals, it can efficiently keep up with reading out an engineering data byte each 64 milliseconds. The engineering telemetry process controls the engineering data analog multiplexer, the analog to digital conversion of the engineering data, the interpreting and scaling the data, and the formatting of the telemetry buffer. A synchronization byte is inserted as the first byte in the engineering telemetry stream. Its purpose is to give the ground station confidence that the altimeter engineering data is in sync with the spacecraft. The last reset time of the altimeter and last command sent to the altimeter is echoed in the engineering data stream.

Conclusion

The diverse requirements for data processing makes the radar altimeter a model for other applications. Similar feedback control processing is required for other types of radars. The dual channel telemetry processing, one synchronous with the spacecraft, and one asynchronous bracket many other interface designs.

ACKNOWLEDGMENTS

A complex instrument like the TOPEX altimeter requires the creativity of many individuals, not only in the hardware and software design of the instrument, but in its analysis, simulation, and evaluation. This work was supported by NASA under contract No. N00039-91-C-0001 to JHU/APL.

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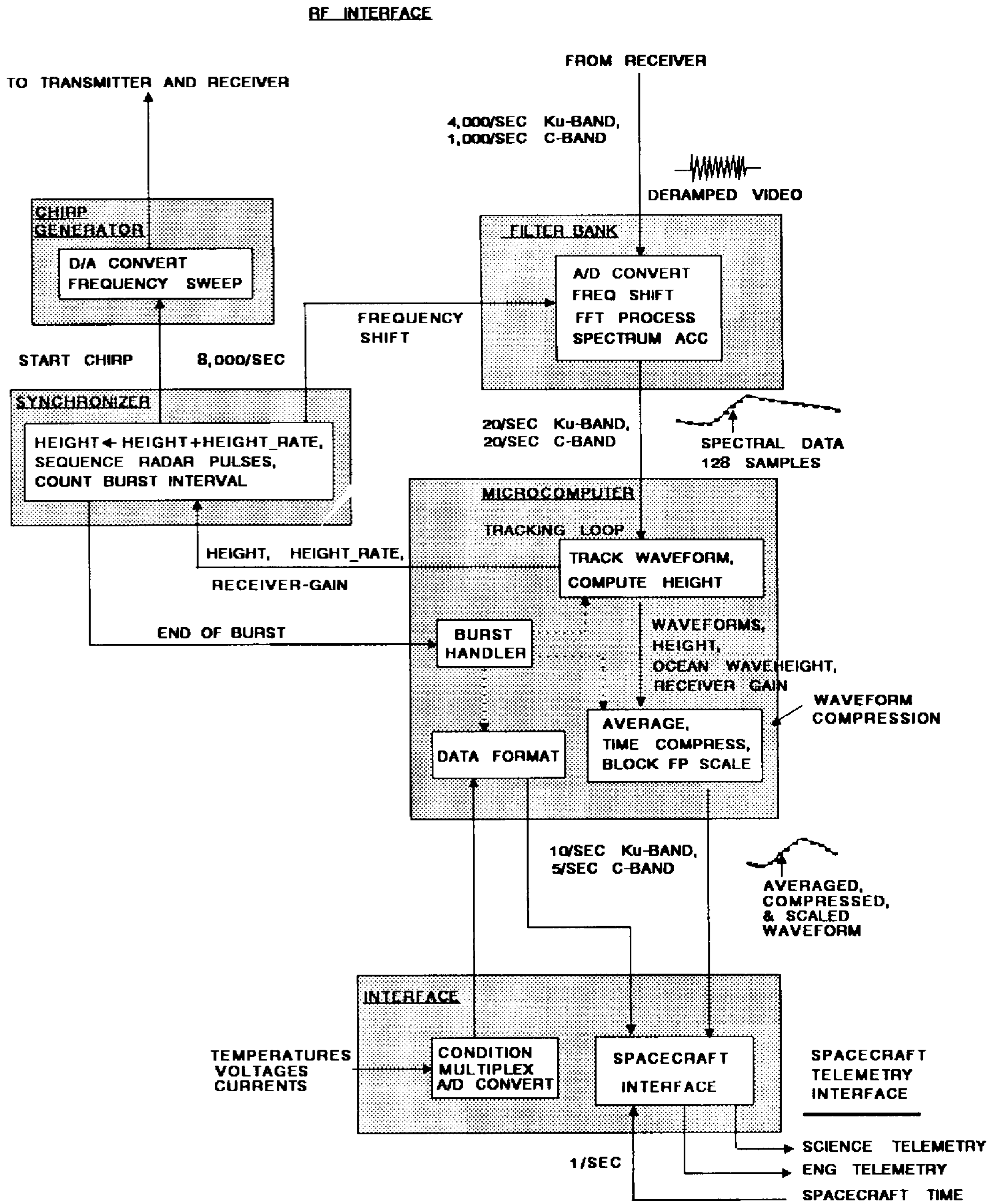

FIGURE 1: TOPEX ALTIMETER DATA PROCESSING