JOHN L. MacARTHUR

SPECTRASAT INSTRUMENT DESIGN USING MAXIMUM HERITAGE

Recent developments in altimeter design for NASA's Ocean Topography Experiment and the Navy's Remote Ocean Sensing System have included enhancements such as dual frequency operation, a variable-bandwidth chirped pulse, a flexible waveform with a high pulse-repetition-frequency burst, and a 16-bit 80186 microprocessor tracker. The new designs, which represent modifications to the proven Seasat and Geosat altimeters, have made it possible to configure a multipurpose instrument for Spectrasat that operates at Ku band as an altimeter and wave spectrometer and at C band as a synthetic aperture radar.

INTRODUCTION

The design of a multipurpose instrument inevitably involves compromises in measurement capabilities. In the case of Spectrasat, the mission concept (as described by Beal in this issue) has eased the problem by permitting interleaved operation between the synthetic aperture radar (SAR) function at C band and the radar altimeter (RA)/radar ocean wave spectrometer (ROWS) functions at Ku band. This allows common receiver and signal processor elements and minimizes the overall weight and power requirement.

A block diagram of the instrument is shown in Fig. 1. The shaded elements represent additions to the basic altimeter to incorporate the added modes. The transmit chain begins with a digital chirp generator that produces linear-FM pulses with a 51.2-microsecond duration and a bandwidth of 80 megahertz or binary submultiples thereof. An up-converter/frequency-multiplier translates this pulse to the desired Ku-band frequency, multiplying by 4 in the process to produce a 320-megahertz bandwidth pulse. The transmitter is the 20-watt traveling-wave tube amplifier used on Geosat. The 7-watt solid-state amplifier being developed for the Navy Remote Ocean Sensing System (NROSS, a program that was cancelled after this article was written) would be more desirable but would not provide sufficient link margin for the spectrometer mode. Most of the Ku-band transmitting power is radiated via a rotating antenna for the spectrometer mode. Ten percent of the power is directed to a 1-meter nadir-looking altimeter antenna. The lower altitude (275 versus 800 kilometers) will result in an adequate link margin for the altimeter. Because the ROWS antenna looks off at 12.5 degrees, the signals reflected from the ocean will be time separated and will allow the 10-decibel coupler to be bypassed for altimeter-signal reception.

The C-band power amplifier will be the 20-watt solid-state version being developed for the Ocean Topography Experiment (TOPEX). However, as an option, higher power modules being developed by the Jet Propulsion Laboratory for the Shuttle Imaging Radar-C mission (see the article by Elachi in this issue) would provide a more comfortable link margin for the SAR mode; in fact, the SAR antenna itself will most likely borrow from the Shuttle Imaging Radar design. Interleaved operation will permit a common receiver chain to be used for Ku band (RA/ROWS) and C band (SAR). The two transmitters will not need to be powered simultaneously. The altimeter signal processor was designed with dual-frequency operation in mind and incorporates an 80186 microprocessor. While some of the SAR and ROWS processing functions can be incorporated into the existing processor, some special-purpose additions, described below, will be required in both cases.

SYSTEM CHARACTERISTICS

Waveform Design

The TOPEX design uses a waveform with a high pulse-repetition-frequency burst in which 102.4-microsecond pulses are transmitted at a fixed rate that can approach 5 kilohertz. At a time slightly less than the two-way time delay to the ocean surface, the burst is interrupted and the timing adjusted so that signals received subsequently fall approximately halfway between transmissions during the next burst. In this way, transmissions and receptions are interleaved to produce a nearly 50 percent duty cycle and to achieve the highest possible pulse repetition frequency for a given pulse width. This technique is illustrated in Fig. 2, adjusted for the proposed Spectrasat altitude. The first return from nadir following a single transmitted pulse will occur at a delay of 1833 microseconds. If the antenna is pointed off-nadir, as with ROWS or SAR, the first re-

John L. MacArthur is a principal staff engineer in the Electronics Systems Branch, The Johns Hopkins University Applied Physics Laboratory, Laurel, MD 20707.

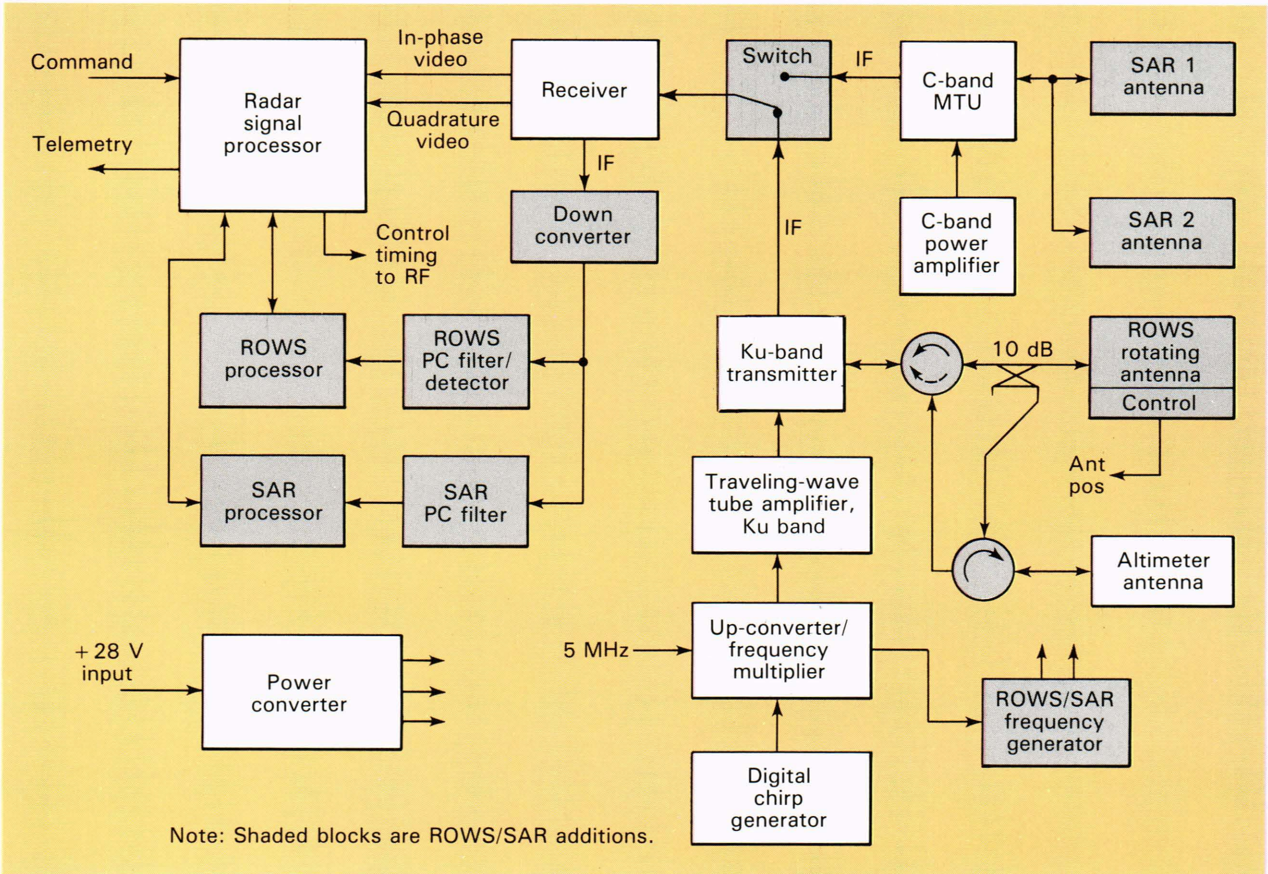

Figure 1—Block diagram of the Spectrasat RA/ROWS/SAR instrument.

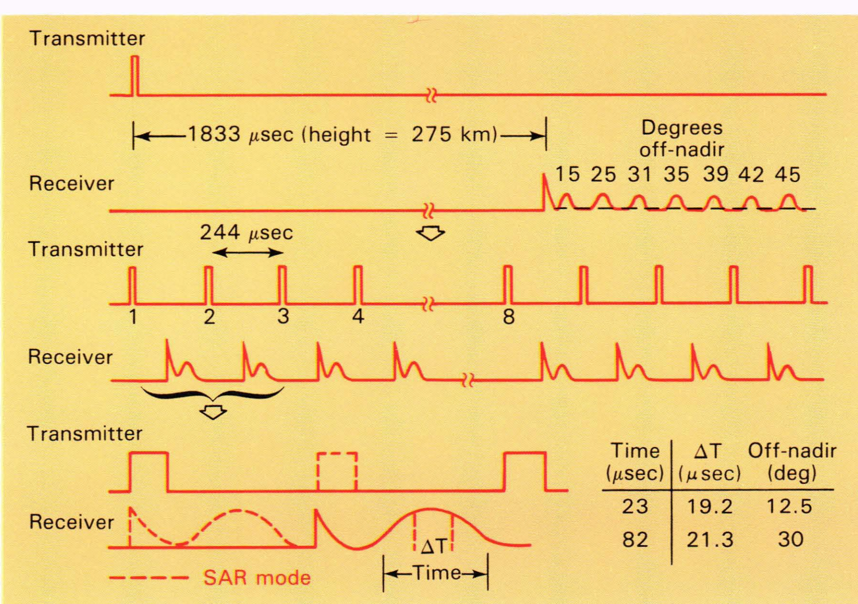

Figure 2—RA/ROWS/SAR timing of transmissions and receptions.

turn will fall at a later time as indicated for the various pointing angles. Now, if a sequence of pulses is transmitted with a 244-microsecond spacing, the nadir (altimeter) return will fall half-way between transmissions, and the off-nadir returns will fall either just after or just before the nadir return. The ROWS antenna will look off at 12.5 degrees, but the nadir return has a very short duration and interleaved RA/ROWS reception will be possible as required. In the SAR mode, there is no restriction on transmitting during reception of the nadir return, and the pulse rate can be doubled as indicated by the dashed lines. The pointing angles that can be accommodated for the SAR mode will then be as shown (15, 25, ..., 45 degrees). Note that in the RA/ROWS mode, the timing will actually be adjusted in 12.5-nanosecond increments following every eighth pulse as part of the altimeter coarse-tracking loop. The design does not permit adjusting the pulse repetition frequency in fine enough increments to achieve this result. The pulse repetition frequency is adjusted in coarser increments to maintain the approximate timing required between transmission and reception, and the best-matching fixed-pulse-repetition frequency derived from altimeter tracking will be used in the SAR mode. The minimum pulse repetition frequency for the SAR with the proposed 3-meter antenna is 5 kilohertz; thus operation of the SAR at a high pulse repetition frequency is essential.

Table 1—Main characteristics of the RA/ROWS/SAR instrument.

	RA	*ROWS*	*SAR*
Frequency (GHz)	13.6	13.6	5.3
Peak power (W)	2	18	20–100
Pulse width (μsec)	51.2	9.6	15
Bandwidth (MHz)	320	60	12
Pulse rate (Hz)	4098	4098	8197
Antenna size (m)	1	0.5 × 1	1 × 3
Gain (dB)	40.8	37.8	39.5
Beamwidth (deg)	1.6	3.2 × 1.6	3.8 × 1.3
Scan rate (deg/sec)	–	36	–
Approximate size (in)		56 × 34 × 8.5	
Weight (lb)		250	
Power (W)		200	
Data rate (kb/sec)		8.5	

Major Characteristics

The main features of the combined instrument are given in Table 1. The pulse width in the altimeter mode is reduced from 102.4 (TOPEX/NROSS) to 51.2 microseconds in order to provide sufficient time between pulses for ROWS reception. Even though the same 320-megahertz-bandwidth transmit pulse is used for RA and ROWS, the effective width for ROWS is reduced to 9.6 microseconds by filtering on reception to a 60-megahertz bandwidth; this reduces the effective pulse energy but still allows adequate link margin. The choice of ROWS bandwidth and effective pulse length is dictated by the availability of dispersive filter devices with the required time–bandwidth product. If a wider time–bandwidth product and effective pulse length can be used, the link margin is improved and the use of a lower power solid-state transmitter can be reconsidered. The pulse width in the SAR mode was selected to maintain a duty cycle at about 12 percent to match the current TOPEX solid-state amplifier design. In the SAR mode, the digital chirp generator and the up-converter/frequency-multiplier will produce a 51.2-microsecond pulse with a 40-megahertz bandwidth. The central 15 microseconds of the pulse will be gated out and transmitted at C band with a 12-megahertz bandwidth. At a 30-degree look angle, the resulting ground resolution in range will be 25 meters. The size, weight, power, and data rate have been scaled from current altimeter designs but should be considered only preliminary estimates.

Receiver Design

The manner in which a common receiver element is used for all three operating modes is further illustrated in Fig. 3. The intermediate frequency is 500 megahertz, obtained by mixing received signals with an appropriate local oscillator. In the altimeter mode, the local oscillator is a chirped pulse that matches the transmitted chirp to implement full-deramp processing and to transform range offset to frequency offset. At all other times,

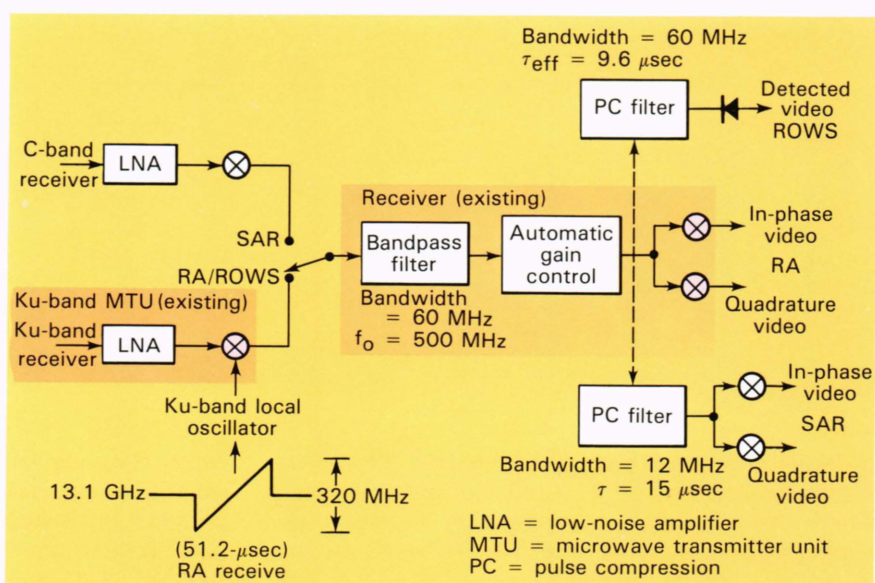

Figure 3—Common receiver characteristics of the RA/ROWS/SAR instrument.

the Ku-band local oscillator is a continuous-wave signal to process the off-nadir ROWS returns. Bandpass filtering in the receiver will pass only the central 60 megahertz of the received pulses, which will have no effect on the RA and SAR operation but will limit the ROWS effective pulse length to 9.6 microseconds. The automatic-gain-control function can be switched rapidly under signal processor control to normalize signal levels as required for the three modes.

ROWS Processor

The ROWS processor (Fig. 4) is essentially a range bin integrator that collects data in 512 cells at a 37.5-nanosecond spacing over a 1/20-second interval (about 200 radar pulses). The samples will have a 25-meter separation on the ground at the 12.5-degree look angle; thus the total span will be 12.8 kilometers. The result is a smooth profile of received power versus range, whose spectral content is related to the ocean-wave spectrum. The ROWS processor interfaces with the existing altimeter 80186 processor and receives information to control the timing of the data collection window. As a function of antenna pointing angle, the range bin timing must be slipped during a data collection interval to account for spacecraft velocity (and earth rotation). By combining the 256 frequency terms into contiguous averages selected to maintain an approximately constant percentage bandwidth, the data rate required for the ROWS can be reduced; this will be accomplished in the altimeter processor during telemetry formating (the basic data sampling rate of the altimeter is 20 per second).

A concept for the ROWS scanning antenna is shown in Fig. 5. A cassegrain design is used so that only the reflector rotates at the 36-degrees-per-second rate. The feed is offset from the axis of the parabolic reflector to produce the 12.5-degree look angle, and the reflector is truncated to produce the desired 1 × 0.5 meter aperture.

The SAR Processor

Figure 6 is a functional block diagram of the SAR processor. Basically, the processor generates 6.4 × 6.4-kilometer images with a 25-meter ground resolution (256 × 256 samples) that are transformed into two-dimensional wavenumber spectra of the ocean surface. On-board clutter-locking will be implemented to correct for earth rotation and yaw pointing errors and to permit presumming prior to image processing. The range rate inferred from the clutter-locking process will be used to slip the timing of the range samples to fix their location on the surface. An azimuth resolution of 12 meters will allow two looks at an overall 25-meter resolution; this may be accomplished with a presum ratio of 13 and an integration time of 0.08 second. The effective azimuth compression ratio is a modest 50:1. The limited swath and resolution combine to make on-board processing feasible. Using fast Fourier transform techniques, it will be possible to perform azimuth compression and image transformation at a clock speed of less than 10 megahertz. The range compression block will not be required if a dispersive filter compressor is used in the receiver, as has been indicated in Fig. 3. An alternate approach would use digital correlators for range compression. That approach would be more adaptible to varying the compression ratio for other applications. Because of the low

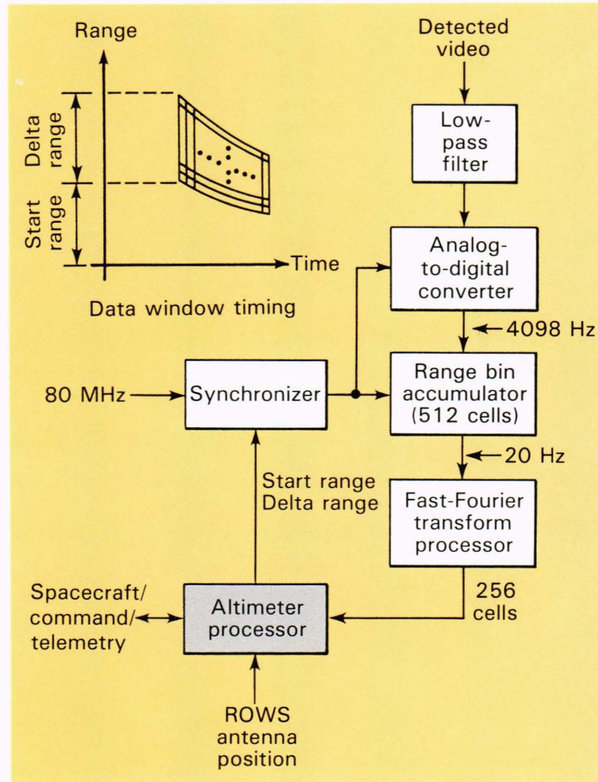

Figure 4—The ROWS processor.

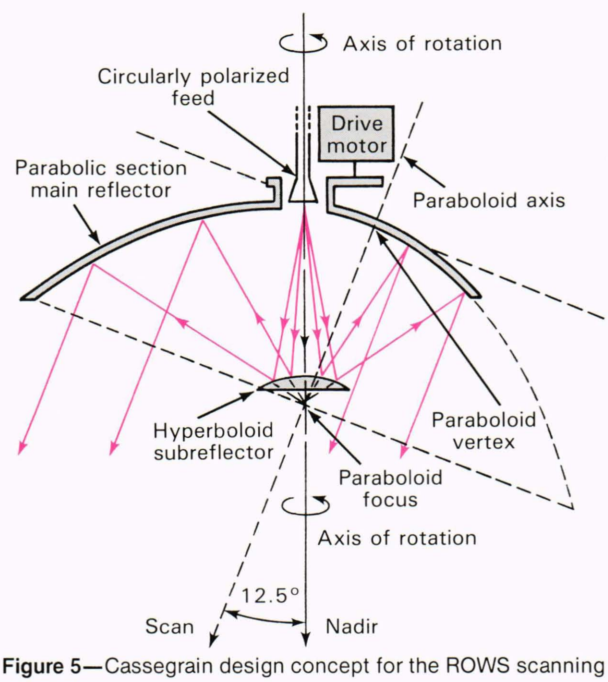

Figure 5—Cassegrain design concept for the ROWS scanning antenna.

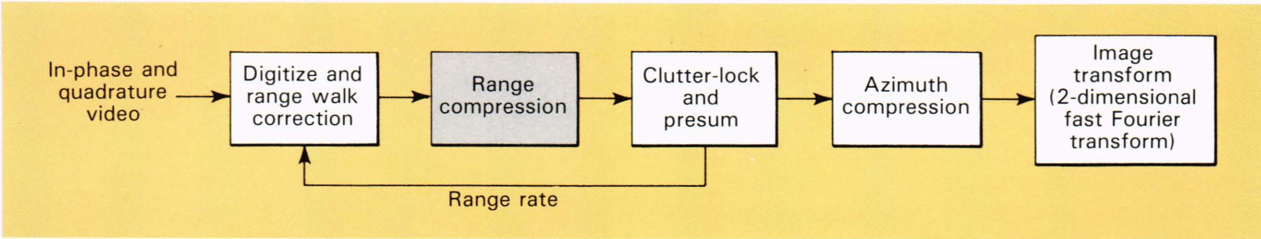

Figure 6—Functional block diagram of the SAR processor.

contrast of the scenes of interest, 1-bit in-phase and quadrature video processing can be used at least up to the point of range compression, thus further simplifying the design.

SUMMARY AND CONCLUSIONS

By expanding on the capabilities of the existing altimeter designs for TOPEX and NROSS, the implementation of a multipurpose instrument to support altimetry, wave spectrometry, and synthetic aperture processing on Spectrasat appears feasible. The key to this is the fact that time-interleaved operation allows several subsystems to be shared among the three operating modes. Furthermore, the existing 80186-based altimeter processor has sufficient reserve processing capacity to act as a central controller and to assume some of the processing tasks.

ACKNOWLEDGMENT—This design effort was supported by APL Independent Research and Development funds.