GROUND STATION EQUIPMENT FOR THE SEASAT SAR

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To receive and use the wideband data signals from the SEASAT SAR successfully, the ground-station receiving equipment had to perform a variety of unique functions.

Introduction

The SEASAT Synthetic Aperture Radar (SAR) provided technical challenges in several areas. Never before did radar developers fly a SAR in space, were radar data processors faced by so much data, or did users have an opportunity to apply the data from a spaceborne unit to their specific needs. Prior to final data processing and user application, the data had to be sent from the spacecraft to the ground and put into a form for transmission to the data processing center at Cal Tech's Jet Propulsion Laboratory (JPL).

The data occupied 19 MHz of bandwidth. The amplitude and phase relationships between all the sampled components had to be preserved with very close tolerances in order to permit the proper reconstruction by synthetic aperture of the radar echoes. Existing NASA ground station receivers were limited to a useful bandwidth of between 20 and 30 MHz. These facts presented even the data downlink with a technical challenge: transmit the data with minimum amplitude and phase distortion without exceeding the bandwidth of the existing ground receivers and record them on specified digital recorders having a maximum bit rate capability of between 120 and 150 million bits per second (Mb/s).

In order to satisfy the bandwidth limitation, APL proposed to the SEASAT program management that an analog downlink be used and that it be a direct translation from baseband to the carrier rather than an amplitude or angle modulation technique that would increase the transmitted bandwidth by creating sidebands on both sides of the carrier frequency.

JPL subsequently chose the downlink approach proposed by APL and assigned development and construction of the data link to APL. The assignment consisted of designing and constructing the portion of the data link within the spacecraft as well as the special demodulator on the ground that would restore the signal to the form it had prior to modulation in the spacecraft. The special demodulator was also to provide reference and synchronizing signals corresponding to those available from the radar equipment in the satellite. (The satellite portion of the SAR data link and the special demodulator are described elsewhere in this issue of the Digest.)

NASA's Goddard Space Flight Center (GSFC) was responsible for recording the downlink data on a digital recorder having a high data rate. In addition, GSFC wanted to devise a quick and simple way to test the ground station equipment in order to ensure maintenance of the tight amplitude and phase tolerances. APL was asked to do the work necessary to meet both of these requirements.

In general, the approach used in preparing the analog data for recording on a digital tape recorder was to sample the data and convert them to digital form with a high-rate analog-to-digital (A/D) converter. For the sample form of any signal to represent faithfully the incoming data, the sampling rate must exceed twice the highest frequency in the incoming signal. In order that simple filtering techniques can be used, it is preferred that the sampling rate be increased to at least three to four times the

signal frequency, but this could not be done at the time.

There had been a prior decision by the designers and users of SAR that the data would be quantized to five bits. To avoid exceeding the recorder's data rate capability of 150 Mb/s, this places an upper bound of 30 million samples per second (Ms/s). However the 19-MHz data bandwidth theoretically requires a minimum sampling rate of 38 Ms/s. This apparent dilemma was resolved by the compromise of taking 5-bit samples at 45.53 Ms/s (228 Mb/s) during that portion of the radar interval when the echo existed, and by not sampling at all when no important echo existed. The sampling and formatting equipment stored, at the very high rate, the burst of digital data obtained, so that it could be sent continuously at a lower average rate acceptable to the recorder; a continuous rate of 117.5 Mb/s was used that is compatible with the high-data-rate digital tape recorder developed separately for GSFC by Martin Marietta.

There were some control functions associated with the formatter in addition to preparing the data for recording. When the satellite altitude changed because of a slight ellipticity of the orbit or because the earth is not perfectly spherical, the radar pulse repetition rate was changed and the time during the pulse repetition interval when the radar echo was sampled was also changed. Appropriate precomputed commands for the spaceborne equipment were transmitted to the spacecraft, along with other operational commands. The downlink ground equipment received corresponding pulse repetition frequency and time delay commands. The equipment designed by APL for GSFC received these ground station commands and, at the appropriate times, forwarded them to the downlink demodulator built by APL for JPL.

In order to satisfy the test requirement for quickly verifying that the tracking station systems involved in receiving synthetic aperture signals were within tolerance, it was decided to use a signal identical to the one the radar would produce if it were receiving from a point target. The signal would pass through whatever portions of the equipment were selected and then it would be time-compressed to provide an extremely narrow pulse with known width, height, and side lobe characteristics. Any amplitude, phase, or time-delay distortion would cause an easily visible effect on an oscilloscope presentation of the compressed pulse.

Figure 1 shows the SAR system on the satellite and at a ground station. The elements marked "STDN" are parts of the normal NASA Spaceflight Tracking and Data Network ground station; the equipment discussed in this paper is crosshatched.

The Data Formatter

The SAR data formatter digitized the offset video radar returns supplied by the link demodulator. These returns had frequency components in the band from 2 to 21 MHz. The 5-bit digital samples were taken at a rate of 45.53 Ms/s, determined by a sampling clock derived coherently from downlink signals by the demodulator. To reduce the burst data rate of 228 Mb/s to the average rate of 117.5 Mb/s that the recorder would accept, the data had to be deleted from the portion of the pulse repetition interval that was of no interest.

Sampling of the radar return of each pulse interval was begun unambiguously at a time determined by a delayed coherent trigger pulse that was
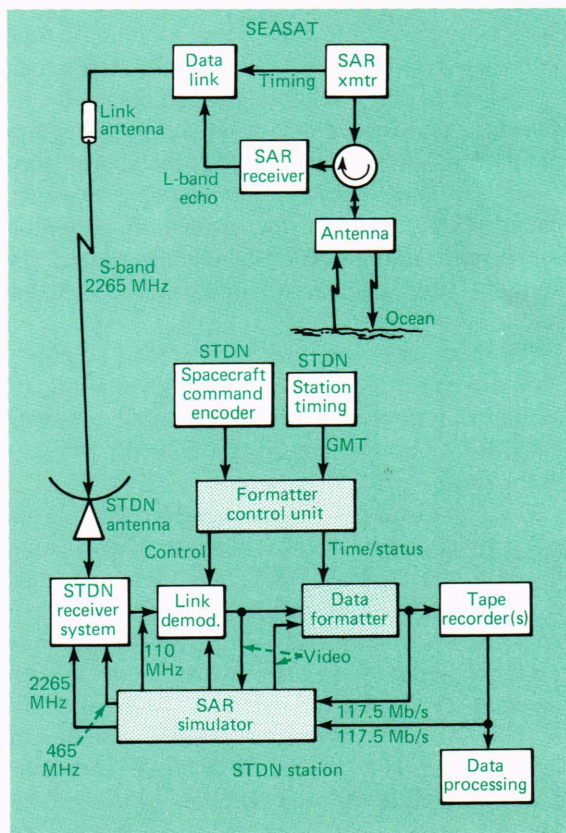

Fig. 1—The SEASAT SAR system.

also supplied by the demodulator. The formatter was also required to receive and format status and time data from two sources and to combine these data with the digitized video samples into a continuous serial data stream.

In the initial system design, it was desired to have the option of selecting 1, 2, 3, 4, or 5 bits per sample. This became an engineering requirement for the formatter; however, analog-to-digital conversion was actually always used at 5 bits per sample. Since the input and output data rates were significantly different, the formatter contains a buffer memory able to store all the digitized video samples from a single radar pulse and then clock them out continuously to the recorder in time to start over with the next radar pulse interval. The data formatter is also able to receive simulated video, sampling clock, and coherent trigger inputs from the simulator, and to supply output data to the simulator for test and evaluation.

The Formatter Control Unit

The formatter control unit is a fixed (wired) interrupt-driven system that stores a block of time-sequenced commands provided by the station control center before a satellite pass. In operation, the time tag for each command is compared against Greenwich Mean Time (GMT), the station time. When the times agree, the command is executed. The four basic functions performed are conditioning and processing of the GMT input signal to the station, command loading, storage and control, and output timing.

There are two possible ways to load command data into the control unit: remotely via automatic station equipment (the GSFC spacecraft command encoder) or by the front panel controls provided on the unit.

The command list was prepared by GSFC prior to a satellite pass and was used to control automatically the SEASAT SAR demodulator located at the STDN stations before and during passes of the SAR. Prior to a SAR pass, all SAR pulse-repetition frequency and coherent-trigger delay commands to be executed by SEASAT were identified by GSFC; the appropriate STDN station was then directed to set up the STDN SAR equipment to be compatible with the satellite at the predicted time for signal acquisition. If, during a pass, the satellite executed an onboard command to change the radar pulse rate or delay settings, the ground STDN equipment was simultaneously changed to be compatible with the satellite. This operation included the following steps:

1. The Mission Planning System at JPL developed the pass sequence for a selected SAR station using long-range orbit predictions.

2. This sequence was sent to GSFC where it was translated into commands for the SEASAT satellite and the ground station.

3. The satellite commands were then formatted into blocks for transmission to the STDN station prior to the pass. Also, the radar pulse rate and delay commands were identified and translated into the time-ordered format for the station control unit. The time for each station control statement was compensated to the nearest second for the computed offset between the satellite and GMT at the station. The command statements were formatted for transmission and sent to the SAR STDN station during the prepass countdown.

4. At the SAR STDN station, the commands for transmission to the satellite and the SAR demodulator control statements were passed to the station's command equipment. The satellite commands were transmitted to the satellite immediately upon receipt. The ground equipment control statements were forwarded to the formatter control unit prior to the pass, but not necessarily as soon as they were received. If desired, this process could be used to prepare a list of commands for transmission to the STDN station via teletype; the list would then be loaded manually into the control unit by the station operator. (This was the method used at the two non-NASA stations at Shoe Cove, Newfoundland, and Oakhanger, England.)

5. The SAR demodulator control statements from the automatic station equipment were supplied to the control unit as a serial stream of digital bits at a nominal rate of 2 kb/s. (The control unit memory had a capacity for 512 32-bit commands, although a maximum of only 64 32-bit commands was expected for each satellite pass.)

6. At the end of the command loading process, the operator checked for load error indications and selected the starting address. The unit was then ready to command the SAR demodulator.

7. When the time stored with each command matched the station time, the command data from the memory address were sent to the demodulator for use and to the formatter so that the status could be included in the recorded data stream.

The SAR Simulator

Two features of NASA's SAR ground-support system differ in important ways from other telemetry systems supported by the STDN. First, the SAR return data passed through most of the STDN equipment in analog form. Therefore, most of the station equipment had to meet analog specifications characteristic of a high-resolution SAR, some of which are difficult and tedious to verify at a station. Second, the eventual digitizing of the SAR return resulted in very high data rates for the formatting and recording equipment.

GSFC asked APL to develop special test equipment to use at network stations so that it would be relatively easy to check out and do end-to-end readiness and maintenance testing of the receiving station portion of the SAR data link.

The output of the SAR antenna was applied to the SAR data link, which linearly translated the L-band returns to 2265 MHz (S band) and added coherent pilot and pseudorandom-noise-encoded radar pulse-rate signals for maintenance of phase and timing references. This composite signal was radiated to the selected ground station.

The actual radar target echo occupied less than half of the interpulse interval; its position within that interval depended on orbit altitude and pulse repetition frequency (PRF). A narrow RF pulse that occurred at the PRF resulted from leakage of the radar transmission through the isolation circuitry of the radar receiver. Random noise from the SAR receiver was present during the entire interpulse interval at a level determined by the gain setting of the spacecraft radar receiver. Also present during the entire interpulse interval were the pilot and pseudorandom noise (PRN) signals added by the data link.

The microwave data-link signal was received by an antenna at the NASA STDN station and was amplified by a low-noise parametric amplifier. The signal was converted to a lower radio frequency and applied to a phase-locked receiver that tracked and performed an automatic gain control function using the pilot component of the composite data-link signal. The output of this receiver was applied to the special SAR data-link demodulator that decoded the PRN signal and reconstituted coherent echo, PRF, and sample clock signals required by the recorder formatting equipment. The radar echo from the demodulator was an offset video signal with a bandwidth of 19 MHz centered at 11.4 MHz.

The output of the demodulator offset video was applied to the SAR data formatting and recording system just described. The digital tapes were transported to a JPL data processing facility where the digital data were played back and converted to images.

Signal Generation

Generation of the simulator signal provided chirped (swept-frequency) signals, a pilot signal, a PRN-encoded signal, and simulated return noise, all at a 91 MHz center frequency and with amplitudes in the same proportions as the components of the SAR data-link signal. They could all be combined to form the composite test signal, or certain ones could be deleted if a test required a simpler signal, for a total of five combinations. The 91-MHz compositely modulated signal was translated to one of the four NASA-site interface frequencies (2265, 465, 110, and 11.4 MHz) for injection into the point in the station equipment selected by the operator.

The chirp generator of the transmitter provided signals that simulated radar leakage and a point-target return. It used a surface acoustic wave dispersive delay line (SAW DDL) from the same mask that was used to make the satellite SAR DDL. Because the center frequency of the satellite-borne device was 91 MHz, all transmitter composite signals were initially generated at that frequency and were then mixed to one of the four required output frequencies.

Within the chirp generator, a high-speed switch gated 1.5 cycles of the 91 MHz signal from the transmitter-frequency synthesizer into the SAW DDL. This resulted in a DDL RF impulse input with a broad spectrum centered at 91 MHz. In a SAW DDL, different frequencies have different propagation velocities. The higher frequencies of the input RF impulse spectrum ($\sim$100 MHz) emerge first and the lower frequencies ($\sim$80 MHz) appear after about 34 μs. The 16-ns input RF impulse is therefore spread in time at the output by more than 34 μs and the output is chirped.

After amplification and limiting, the time-spread

signal goes to a second gate circuit where it is sliced at exactly ±17 μs, corresponding to a frequency span of ±9.5 MHz about 91 MHz.

The transmitter used coding circuitry similar to that of the spacecraft data link to provide a PRN-encoded PRF signal identical to that on the spacecraft. The modulation/summing circuitry within the transmitter modulated the PRN code onto the pilot frequency with equal pilot and PRN levels. It then summed the modulation components into a composite modulated signal that was converted to the selected output frequency.

As is shown in Fig. 1, the transmitter output could be injected at several points along the chain of SAR ground equipment. Similarly, the analog or digital signals from the ground equipment could be switched into the receiving and processing circuitry of the SAR simulator for measurement and evaluation. When receiving signals in digital form, a video regenerator was used to perform the inverse function of the SAR data formatter described previously.

Signal Processing

The video regenerator received the 117.5 Mb/s digital stream either from the data formatter or from the recorder playback. It used a frame synchronizer built with high-speed emitter-coupled logic to achieve synchronization with the data in the bit stream. It then picked out and displayed time and status data, buffered the digital samples of offset video, and converted the samples to bursts of analog offset video at the full rate of 45.53 Ms/s. This recreated the original analog radar burst. A special APL design of a digital-to-analog converter was used to achieve conversion with intersample settling times of about 4 ns.

The simulator provided for time inversion of the input to a second, identical, DDL so that pulse compression could take place. For the ideal case, the DDL output is the autocorrelation function of the input signal. Amplitude and phase distortions within the simulator and the equipment under test will cause deviations from the ideal shape of the output pulse.

A transversal filter was used to equalize any amplitude and phase distortions of the simulator that occurred within its constraint range and to provide uniform weighting of the signal components in the compressed signal. This uniform transversal filter used only three taps to adjust the width of the compressed pulse at the 3 dB level for resolution measurements. A second transversal filter was selected to provide weighting of the signal component to correspond to the Taylor weighting used on the data when it was processed at JPL. For this filter, the summation of terms was accomplished by adjusting appropriately, relative to the center tap signal, the amplitude and phase of six tapped signals that were summed.

For both transversal filters, the initial adjustment was made to obtain nearly ideal pulse waveforms when the simulator transmitter signal was sent only through the simulator processing circuits. This assured that the simulator itself would not contribute to any indicated errors (as shown by compressed pulse broadening or by high compressed pulse sidelobes).

Figures 2 and 3 show oscilloscope presentations of the compressed pulses after the components have been subjected to Taylor and uniform weighting, respectively. When amplitude or phase distortions occur, they show up as increased or asymmetric lobes in the waveforms as well as easily observed broadening of the pulse waveform's main lobe.

Performance and Testing

When processed within the simulator receiver, the output signal of the simulator transmitter approximated the impulse response of the SAR range channel, which, for the radar, was convolved with surface reflection in the radar image processing. Because the SEASAT SAR system was linear to the first order, the degradations to the impulse response introduced by the STDN support equipment were important descriptors of site performance.
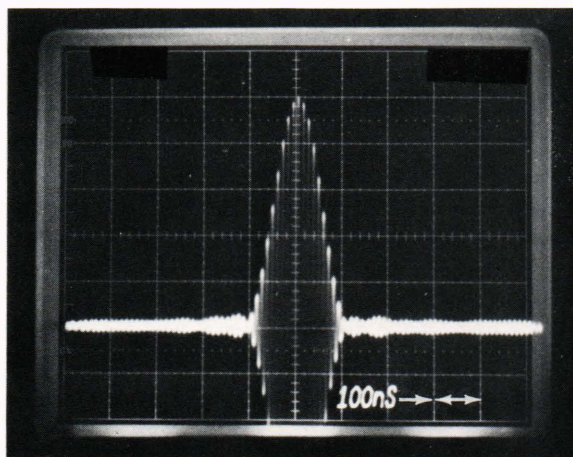

Fig. 2—Taylor-weighted compressed-pulse oscilloscope display. Note the lack of side lobes. If amplitude or phase distortions occur, side lobes would appear.
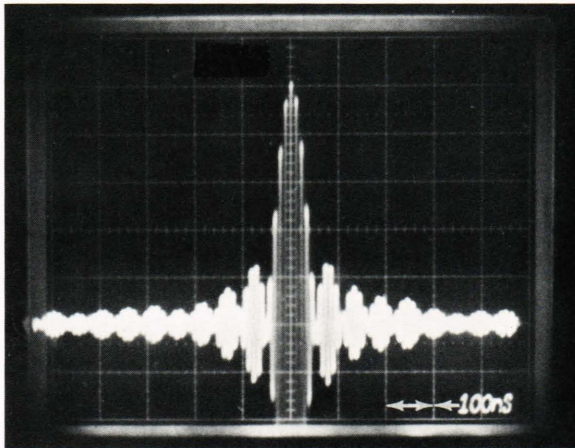
Fig. 3—Uniformly weighted compressed-pulse oscilloscope display. Note the existence of side lobes and the fact that the main lobe is much narrower than in the Taylor-weighted case of Fig. 2. If amplitude or phase distortions occur, the main lobe might become noticeably broader, the side lobes might become asymmetrical, and some side lobes might become larger.

The simulator pulse processor and display were also used in testing the satellite radar itself during tests at Lockheed, the spacecraft prime contractor. Figure 4 shows the special ground equipment built by APL for each ground station.

All three sets of NASA ground station equipment were delivered and in operation within a month of the initial schedule estimates made 21 months earlier. This placed all the NASA equipment in operation at least two months before launch.

During the 3½ months of spacecraft operation, the ground station equipment supplied to the five stations performed reliably and was used to record literally hundreds of data tapes.

What About the Future?

When another SAR is flown, the system designers will have to decide what form their downlink system will take. The approach used for SEASAT was shown to work successfully without too much special station equipment. Each station equipped to receive SAR data was able to receive all the SAR data the satellite obtained from about two to three percent of the earth's surface. The stations were located so that enough useful data were obtained to keep the data processors and data users occupied for a long time.

When the NASA/Western Union Tracking and Data Relay Satellite System (TDRSS) comes into service in the early 1980's, it may be possible to use a broadband digital data link from space to ground that can handle the average data rate of 117.5 Mb/s from the formatter or possibly even the 228 Mb/s peak data rate from the A/D converter. If a future spacecraft were to be served by TDRSS,
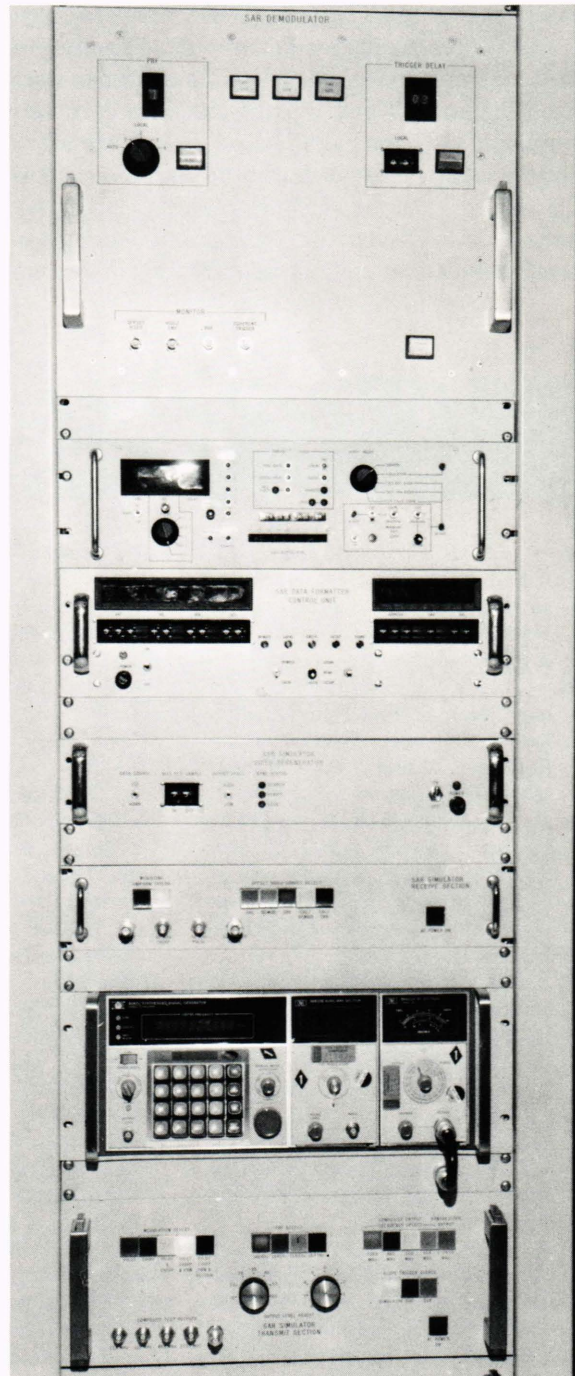

Fig. 4—STDN SEASAT SAR support equipment.

all or some of the formatter functions could be put on the satellite. By using TDRSS, it would be possible to cover oceanic or meteorological events selectively over more than 95% of the earth's surface. (The exact amount of coverage would depend on the satellite's altitude.)

For the present, the high-speed tape recorder, the formatter, and portions of the simulator have found a potential application in medical electronics. Some ultrasonic equipment used in ophthalmology has a bandwidth and a pulse repetition rate very similar to those of the SEASAT SAR. One set of ground equipment that was returned from a tracking station after the satellite stopped working has been used to convert the analog data from ultrasonic ophthalmic equipment into digital form for recording so that the data can be played back into a computer in order to develop sophisticated, digital data-processing techniques for the field of ophthalmology.

Acknowledgments

PUBLICATIONS
Principal books and technical articles published by APL staff members
January—August 1979

F. J. Adrian and A. N. Jette, "Valence Bond Study of Hyperfine Interactions and Structure of Kr_2F," Chem. Phys. Lett. 64, No. 3, pp. 555–559.

R. H. Bauer, "A Wind-Effects Model and Ocean Current Determination for a Satellite Updated Dead Reckoning System," Proc. Annual Meeting, Institute of Navigation.

R. C. Benson and R. A. Meyer (APL) and M. E. Zaruba and G. M. McKhann (JHMI), "Cellular Autofluorescence—Is it Due to Flavins?" J. Histochem. Cytochem. 27, No. 1, pp. 44–48.

F. S. Billig, L. J. Crawford, and C. J. Gundersdorf, "Advanced Oceanographic Instrumentation Systems and Measurements at St. Croix, U.S.V.I.," J. Hydronaut. 13, No. 3, pp. 77–84.

J. F. Bird, "Hydromagnetic Perturbations Due to Localized Flows: An Eddy Theorem," Phys. Fluids 22, No. 3, pp. 585–586.

P. R. Briggs and T. P. Armstrong (Univ. Kansas) and S. M. Krimigis (APL), "Hydrogen over Helium Enhancement in Successive Solar Flare Particle Events from the Same Active Region," Astrophys. J. 228, pp. L83–L87.

F. R. Castella, "Heading and Speed Errors for x,y Tracking Filters," IEEE Trans. Aerosp. Electron. Syst. AES-15, No. 2, pp. 284–287.

H. Y. Chiu, R. M. Somers, and R. C. Benson, "Decomposition of Solid NaN_3 by CO_2 Laser Radiation," Chem. Phys. Lett. 61, No. 1, pp. 203–208.

L. L. Cronvich, "Aerodynamic Development of Fleet Guided Missiles in Navy's Bumblebee Program," Proc. AIAA Aerospace Sciences Meeting, January.

A. J. Dessler (APL) and V. M. Vasyliunas (Max-Planck Inst. für Aeronomie), "The Magnetic Anomaly Model of the Jovian Magnetosphere: Predictions for Voyager," Geophys. Res. Lett. 6, No. 1, pp. 37–40.

L. W. Ehrlich, "A Marching Technique for Nonseparable Equations," Math. Computation 33, No. 147, pp. 881–890.

A. R. Elcrat (Wichita State Univ.) and V. G. Sigillito (APL), "A Spatial Decay Estimate for the Navier-Stokes Equations," ZAMP 30, pp. 449–455.

R. A. Farrell and S. Favin (APL) and J. T. Sullivan, S. Vimolvanich, and P. H. E. Meijer (The Catholic Univ. America), "Coexistence Curves for Fourth-Neighbor Ising Models on the Face-Centered-Cubic Lattice," Phys. Rev. B 19, No. 9, pp. 4703–4710.

R. M. Fristrom (APL) and P. Van Tiggelen (Univ. Louvain, France), "An Interpretation of the Inhibition of C—H—O Flames by C—H—X Compounds," Proc. 17th Combustion Inst. Symp.

J. Goldhirsh, "Predictive Methods for Rain Attenuation Using Radar and In-Situ Measurements Tested Against the 28-GHz Comstar Beacon Signal," IEEE Trans. Antennas Propag. AP-27, No. 3, pp. 398–406.

J. Goldhirsh and I. Katz, "Useful Experimental Results for Earth-Satellite Rain Attenuation Modeling," IEEE Trans. Antennas Propag. AP-27, No. 3, pp. 413–415.

L. W. Hunter, "Models of Horizontal Electric Cables and Cable Trays Exposed to a Fire Plume," Combust. Flame 35, pp. 311–329.

L. W. Hunter and C. Grunfelder, "Heat-Transfer Measurements in the Moving-Wire Technique for Studying Polymer Flammability," Combust. Flame 34, pp. 265–274.