Introduction

Special Issue on Space Shuttle Communications and Tracking

THIS Special Issue is intended to provide for the readers of the ComSoc TRANSACTIONS a reasonably comprehensive description of the various techniques and systems which will provide communications and tracking functions for the Space Shuttle, which is scheduled to begin its Orbital Flight Test phase in 1979 and to be fully operational by 1981.

In the past, perhaps a relatively higher degree of sophistication has been associated with the communications techniques and hardware developed for unmanned space exploration, as opposed to those utilized for manned space flights. The generally higher data rates associated with the voice and television requirements for manned flights have kept the gaps small in some areas; however, most of the more innovative techniques in the areas of data compression, channel coding, and modulation have evolved in support of the unmanned lunar and deep space probes. Now we are entering a transition phase in which two distinct effects on space communications techniques and systems are being experienced, and these effects have required a much higher degree of sophistication for the Shuttle's communications and tracking systems.

First, the era of the low-cost Space-Shuttle-launched and/or recovered payload satellites has resulted in the requirement for mutual communications compatibility between the Shuttle and many of the various unmanned payloads for which it will serve as a host vehicle. Not only will the Shuttle be required to communicate with its own network (ground stations and communications relay satellites) for operational flight support, but it will also have to communicate with and provide communications relay services for these payloads. Likewise, not only must navigation be performed for the Shuttle itself (by use of ground and satellite tracking networks), but the Shuttle will have to track the wide range of unmanned satellites which it deploys and with which it must rendezvous and conduct retrieval operations.

The second effect being experienced in this transition phase is that most communications systems for the various NASA programs must be designed for compatibility with the Tracking and Data Relay Satellite System (TDRSS). Communications satellite support of vehicles in low Earth orbit was demonstrated during the Apollo-Soyuz Test Program in 1975, when the ATS-6 satellite was used experimentally for that purpose. However, in the TDRSS era, such support will be used operationally in lieu of ground station support. To develop TDRSS-compatible systems for the Shuttle which satisfy the data requirements for launch, on-orbit operations and entry has constituted the major problem encountered in the area of Shuttle communications.

To further complicate matters, the ground networks for both NASA and USAF must also be used for operational flight support of the Shuttle, and each of these networks has its own unique characteristics and requirements. For the early Shuttle flights, ground support will be provided by the NASA Spaceflight Tracking and Data Network (STDN) ground stations. These stations closely resemble those of the manned flight network used for past programs such as Apollo, Skylab, and Apollo-Soyuz. For later flights, some of which will be NASA and some USAF, communications support will be provided by the TDRSS (configured with satellites launched by the Shuttle) plus a few NASA ground stations required for support of the ascent and entry mission phases. In addition, the USAF will utilize its own Satellite Control Facility (SCF) ground stations for at least some of the required flight support.

When selecting system approaches to satisfy the various Shuttle communications and tracking requirements, every effort was made to utilize available hardware. In several cases this was possible. The *TACAN* system, to be utilized for post-blackout area navigation during entry, is a military aircraft design (AN/ARN-84) modified to interface with the Shuttle Orbiter avionics. The *Microwave Scanning Beam Landing System* (MSBLS), to be used to provide terminal area navigation, is likewise a military aircraft design (AN/ARQ-31) modified to interface with the Orbiter avionics. The *radar altimeter*, which provides a readout of altitude above the runway, is a military aircraft design (AN/APN-194). The *UHF voice transceiver*, to be utilized for backup voice communications during the early Shuttle flights, is also a standard military design (AN/ARC-150). Unfortunately, "off-the-shelf" type hardware was not available to satisfy the more difficult Shuttle communications requirements. No transponders, signal processors, etc., were available which could provide voice, command and telemetry communications with all three of the networks noted earlier (STDN ground stations, TDRSS, and SCF), and no equipment was even similar enough to be considered for modification. Hence, a major effort was undertaken to develop an S-band PM communications system to provide the necessary capabilities. A lesser effort, relying largely on existing technology, was also undertaken to develop an S-band FM communications system to provide various other downlink services, such as television or tape dumps to ground stations, primarily in the pre-TDRSS era. In addition, no modifiable hardware was available to satisfy the requirements for television and high-rate payload data via the TDRSS, tracking of payloads in the vicinity of the Orbiter, and communications with those payloads. Thus another major effort was undertaken to develop an integrated communications/radar system operating at *Ku*-band, and still another effort was initiated to develop an *S*-band system for communicating with payloads.

This Special Issue of the TRANSACTIONS emphasizes the developmental areas noted above. Several of the papers are non-technical in nature and are included to provide a degree of overview and insight that would be difficult to obtain from papers of a more technical nature. These general papers thus should allow a better understanding of the significance of the detailed technical papers and, additionally, should be of more interest to a wider audience than the detailed ones.

The papers of a more technical nature describe either: (1) the systems which have evolved after several years of design, development, test and evaluation activities, or (2) problems which were encountered during these activities. As noted earlier, several of the Shuttle systems are of relatively "off-the-shelf" design and problems which have been encountered with these systems have been primarily related to physical or electronic integration of the hardware with the Shuttle Orbiter vehicle or to meeting the stringent environmental requirements associated with space qualification of hardware. The more interesting problems have been associated with the development of the more advanced *S*-band and *Ku*-band systems. These systems are more representative of the current state-of-the-art from the following viewpoints:

1. *The S-Band PM Operational Communications System*

This coded, spread spectrum system must operate within 2.5 dB of theoretical, even at signal-to-noise ratios (E_b/N_0's) in the vicinity of zero dB.

2. *The Ku-Band Communications/Radar System*

This high-rate, multichannel, coded, spread spectrum system utilizes a deployable parabolic antenna (36-in diameter) which, along with many other system elements, is shared with a *Ku*-band skin-tracking radar. The 50 Mbit/s channel associated with this system has given rise to numerous problems, primarily because of the high data rate and the low signal-to-noise ratios which are characteristic of the link.

3. *The S-Band Payload Communications System*

This system is now in the final design phase and has proved to be challenging because of the wide variety of data rates and formats, frequencies, and other signal characteristics that are required to provide command transmission and telemetry monitoring for many of the payloads (NASA, DOD, commercial, etc.) which will be deployed and/or retrieved by the Shuttle. This system must provide many of the essential communications services for payloads which in the past have been provided by the NASA STDN, the USAF SCF, and the Deep Space Network.

This issue contains a total of twenty-six papers. The first, by John MacLeod of the Shuttle Program Office at NASA/Johnson Space Center (JSC), provides a general overview of the Space Shuttle Program which is the most comprehensive and up-to-date summary currently available. The second paper, by Lou Carrier and Warren Pope of Rockwell International (RI) Corporation, gives an overall description of each of the communications and tracking subsystems (both shelf-type and developmental in nature) that will be utilized by the Shuttle. The third paper, by Jack Schwartz of NASA/Goddard Space Flight Center and Gene Feinberg of ORI, Inc., describes the NASA communications and tracking network which will be utilized by the Shuttle. The fourth paper, which is the last of the general overview papers, by Emil Schiesser (NASA/JSC), describes how the various RF subsystems onboard the Shuttle Orbiter will fit into the overall navigation scheme for Shuttle operations.

The next four papers are concerned with *S*-band operational communications. The paper by Bob Bacinski and Rich Helgeson of TRW describes the Orbiter hardware which is being developed, while the remaining papers discuss problem areas which were encountered and which are considered to have been largely resolved. The paper by Bill Lindsey of the University of Southern California (USC) and Kwei Tu of Lockheed Electronics Co. (LEC) addresses the effects of phase noise on Shuttle *S*-band communications (including *S*-band links with payloads); the effects of phase noise are certainly not unique to Shuttle, so this paper should be of special interest to many readers. The paper by Marv Simon of the Jet Propulsion Laboratory (JPL) considers what happens when a suppressed-carrier tracking loop is confronted with a signal having a residual-carrier component, as is the case for the Shuttle *S*-band uplink under certain conditions (direct transmission from STDN, when ranging tones are present). The paper by Jack Holmes (JPL) and Leon Biederman (LinCom) evaluates the mean time required for a PN delay-lock loop, such as is utilized by the Shuttle for the *S*-band spread spectrum uplink via TDRSS, to lose lock. Poor in-lock time is a problem for this weak Shuttle link at worst-case signal-to-noise ratios.

The next four papers deal largely with Shuttle payloads which must be communicated with while attached to or free-flying in the vicinity of the Orbiter, and with the Orbiter *S*-band system which is providing much of this communications capability. The paper by Bill Teasdale (NASA/JSC) describes the wide variety of payloads which will be deployed and/or retrieved by the Shuttle, along with the general data handling services which the Orbiter will provide. The paper by Gordon Bolton, Tony Errington, Rudi Selg, and Fred Weijers of the European Space Agency describes the Spacelab communications and data management system which will be the principal source of the high rate data which will be serviced by the Shuttle *Ku*-band 50 Mbit/s channel. The paper by Jim Springett and Serge Udalov of Axiomatix provides a detailed description of the Orbiter *S*-band system which will allow communications with both attached and detached (free-flying) payloads. The paper by Sam Houston, Don Martin, and Larry Stine of TRW describes the microprocessor design approach which has been selected for the bit synchronizer to be utilized by the payload communications system.

The next four papers are related to *Ku*-band communications and radar for the Shuttle. The paper by Ralph Cager, Dave LaFlame and Lowell Parode of Hughes Aircraft Co. describes the developmental *Ku*-band hardware in detail. The paper by Waddah Alem (Axiomatix) and Chuck Weber (USC) gives a performance analysis of Shuttle-type pulse Doppler radars which should be of general interest. The paper by Jim Dunn of Linkabit describes the coding scheme which was conceived for the Shuttle *Ku*-band 50 Mbit/s channel and which was subsequently generalized to provide a 150 Mbit/s capability for all TDRSS high data rate users. The paper by Marv Simon, Kwei Tu, and this Editor evaluates the effects on bit error rate performance of the relatively high data asymmetry levels characteristic of the *Ku*-band 50 Mbit/s channel.

The next group of four papers deals with voice and video encoding techniques either being utilized or being considered for utilization in the Shuttle systems. The paper by Don Schilling of the City College of New York (CCNY), Joe Garodnick of Stern Telecommunications Corp., and Hal Vang of NASA/JSC discusses the adaptive delta modulation technique (and its implementation) which was selected for Shuttle voice transmission. The paper by Bob Auger, Mike Glancy, Mike Goutmann, and Alan Kirsch of the General Atronics Corp. describes the ground terminal hardware which will provide the delta-modulated voice capability for Shuttle. The paper by Ali Habibi of TRW (co-authored by this Editor) describes several encoding techniques which were considered for Shuttle video signals, although Shuttle television transmission still is via analog FM links. The paper by Don Schilling, Norm Scheinberg (CCNY), and Joe Garodnick describes an alternate approach for encoding Shuttle television. This scheme is particularly attractive for potential implementation because of the high picture quality and extremely low complexity of the hardware.

The last six papers of this issue deal with topics which do not fit directly into any one of the above categories. The paper by Waddah Alem, Gaylord Huth (Axiomatix), Jack Holmes, and Serge Udalov describes acquisition and tracking performance of the spread spectrum systems utilized by the *S*-band and *Ku*-band network communications links. The paper by K. T. Woo (JPL), Gaylord Huth, Bill Lindsey, and Jack Holmes discusses the false lock phenomenon associated with the Shuttle *S*-band and *Ku*-band Costas loop receivers. The paper by Dean Cubley (NASA/JSC) and Haynes Ellis (RI) discusses the various antenna development programs which were necessary for the Shuttle, and describes the approaches utilized to verify performance of the large number of antennas which will be installed on the Orbiter. The paper by Bill Lindsey and Walter Braun (LinCom) discusses a simulation capability which was developed to evaluate and verify performance for the weak Shuttle/TDRSS communications links. The paper by Jack Seyl and Don Travis of NASA/JSC describes the approach utilized by NASA to verify the compatibility and performance of Shuttle communications links by hardware measurements. The paper by Y. C. Loh (LEC) and Jim Porter (NASA/JSC) discusses how the results of analysis, simulation, and test activities are utilized in predicting how the various communications links will actually perform during Shuttle missions.

I would like to express my appreciation to the many individuals who contributed to this Special Issue by preparing and reviewing papers. Special acknowledgment is extended to Dr. Kwei Tu, who not only co-authored two papers, but also assisted in the review and coordination process for most of the other papers.

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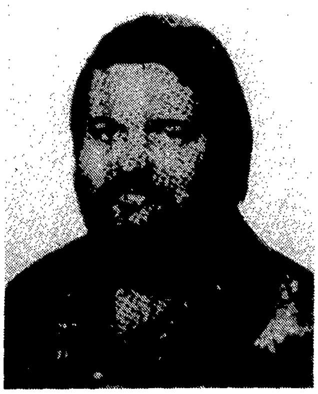

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