ADVANCED COMMUNICATIONS EXPERIMENTS
FOR SPACELAB*

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Summary. The joint NASA-ESA Spacelab project offers the space engineer the opportunity to develop and test advanced communications technology in a new environment. The large volume and weight carrying capability of the Spacelab, plus the presence of an astronaut-engineer, means that large-diameter deployable antennas can be developed; multiple antennas operating at differing frequencies can be employed for propagation experiments and the detection of radio frequency noise sources on earth; and comparative, side-by-side telemetry experiments can be performed employing differing modulation techniques. The zero-gravity, high altitude and frequent flights into space make Spacelab a new tool for the communication engineer to employ for telemetry/communications research.

Introduction. A new era in space communications technology research, development and testing will be available to engineers and scientists in the early 1980’s when the NASA European Space Agency (ESA) developed Spacelab will become a reality. This experiment-carrier resides within the Space Shuttle orbiter payload bay. It consists of a pressurized, shirt-sleeve environment laboratory where astronauts may move around and conduct experiments, eat, sleep and observe. It is from this laboratory that extra-vehicular activities (EVA) will originate, where analysis of records and/or instruments will take place and where human and animal biological and physiological experiments will be performed. Spacelab also consists of an unpressurized element called “the pallet.” The pallet is where instruments requiring exposure to space will reside. Thus, communications antennas, laser telescopes, optical telescopes, etc. will be carried on the pallet.

A Spacelab mission may consist entirely of a pressurized laboratory or entirely of a pallet, or as is expected to be the majority of missions, a combination of the two. Pallet elements are planned to be made up of 3 meter long units, and upwards of 5 units may be joined together for an all pallet mission. Pressurized laboratories of 9-10 meter lengths are possible.

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Spacelab will fit within the Space Shuttle’s bay envelope which is 18 meters long and 4-1/2 meters in diameter. With the payload bay doors and radiators open, there is an unobstructed 180 deg lateral field of view, except for local interference, for any point within the bay 0.7 meters above the center line. The bay is vented during launch and entry phases and operates unpressurized during the operational phase of the mission. Contamination may arise from particulates emanating from the Orbiter. The overall sound level will not exceed 155 dB and the random vibration levels for the mid-fuselage section of the Orbiter will be 12-28 g, RMS, from 20 to 2000 Hz.

Spacelab will carry from 4,000 to 11,000 kilograms of experiment hardware and experiment peculiar integration equipment into approximately 200-400 kilometer orbits for upwards of seven days during its early missions. It will also be able to return with its complete instrument cargo. Thus experimenters desiring data on the space effects on instrument performance will be able to get their wish. Laser telescopes will have their optics checked, communication tubes opened to the low vacuum of space can have their cathodes examined in a ground based laboratory, and the distortion (if any) of antenna structures can be evaluated.

The initial Spacelab missions will be from the Eastern Test Range, starting in 1980, with inclinations of 28.5 to 57 deg. In 1983 the Western Test Range may be available for Shuttle launches, with inclination limits of 56 to 104 deg. The orbital altitude to which the Shuttle can deliver a payload depends upon the size of the payload and the inclination. Without a payload the Shuttle can reach a circular altitude of 1250 Km and with a payload of 30,000 kg, it can reach a circular altitude of 400 Km (assuming an ETR launch).

It is obvious that essentially all communications instruments require an earth-pointing orientation of the Shuttle as much of the time as possible. At least the worst-case earth pointing for two-thirds of the time specified for Shuttle Sortie flights would generally be needed. This means that some primary payloads would not be compatible with the addition of an experimental earth sensor. Most obvious of these are laser payloads, which would probably demand inertial pointing.

The electrical power is obtained from a Shuttle fuel cell giving 7 Kw average and 12 Kw peak power, at 28 + 7 VDC. Alternating current will probably also be available at 400 Hz, 115/200 V.

The number of Shuttle/Spacelab missions planned per year varies from three to eight during the early years of Shuttle operation. Of these, the astronomy and physics missions are probably incompatible with earth looking communications experiment development because of fundamentally different pointing requirements. However, during the first five years of operation (1980 - 1984) there may be four presumably suitable Spacelab missions.
each year. Two turn-around cycles (time between landing and takeoff) have been suggested - a standard turn-around of 34 days and a short turn-around of 14 days.

**Experimental Payloads**

The Spacelab design and mission capability appear to provide a practical vehicle for meeting communication experiment needs and for conducting experiments that: will benefit from the presence of an experimenter in space; require close observation of structural deployments; or require major radio frequency antenna changes. The Sortie mode of operation will also reduce the time, risk and cost for conducting certain short term experiments and for developing the space technology which may lead to eventual automated system application. The heavy payload capability feature of Spacelab facilitates comparative test evaluation between alternative subsystems, components and techniques. Finally, the Shuttle-Spacelab payload return capability not only enables the experimenter to perform an evaluation of the effects of the space environment on his experiments, but perform it in the comfort of his ground-based laboratory.

NASA, in its role as the developer of advanced space communications technology for the civilian community, has tried to obtain the best advise and suggestions from the technical community-within its own organization and outside, as to the communications technology that Spacelab should develop. Examples of this advise range from the NASA-Industry-University team that provided one of the early documents on the use of a space laboratory for communications and navigation in May 1973\(^{(1)}\); to the National Academy of Engineering 1974 Summer Study on Space Application\(^{(2)}\); to a 60 member Government, Industry, University workshop on Shuttle Communications Experiments that met in June 1974\(^{(3)}\). The results of these meetings and the results of numerous contractual activities during the last few years\(^{(4)}\), have shown conclusively the potential useful role that a manned laboratory in space will afford to the communications community.

Some examples of the experiments that today appear to be strong candidates for early flights on the Spacelab missions of the 80’s follow:

A. **Radio Frequency Interference (RFI)**

During recent years, increased radio frequency (RF) usage has created spectrum-resource problems for the various regulatory agencies. Since spectrum occupancy is expected to experience an ever increasing growth in the future, a capability for providing continuous global spectrum monitoring and electromagnetic environment mapping is essential in order to avoid overcrowding and interference in particular bands. With the advent of the Spacelab program the opportunity for developing the space technology and to perform space-monitoring RF environment surveys can be accomplished. Figure 1 depicts conceptually this experiment on Spacelab.
The RF survey program will establish both a system and a data base for determining limits on interference in crowded spectral bands and updated listings of those bands void of interference. This type of information will then become available to both NASA and the various regulatory US and foreign agencies. Based on this resultant survey data, more efficient spectrum usage should accrue in the future. The spaceborne survey system may also provide mapping of certain geographical areas that would have been impractical to achieve via terrestrial methods and levels or limits of earth-to-space RF emissions on a global basis. Finally, this type of data will place the U.S. in a more informed position regarding negotiations for international frequency allocations at future meetings.

The heart of the experiment will be the RFI receiver. It will be a frequency scanning device, digitally stepping through its total frequency coverage. The frequency measurement error will be equal to or less than the local oscillator error pulse one-half the sample increment plus broadening due to the pass-band filter skirts. For full coverage of the spatial swath, the entire designed frequency range must be covered at all antenna footprints across the swath. With an electronically scanned phased array, about 36 milliseconds per step is available, assuming instantaneous stepping. With a DF system looking at the entire $2.4 \times 100$° swath segment at once, 1.5 seconds are available to cover the required frequency band.

Due to RF bandwidth limitations of antennas and other RF components, only a few desired frequency bands can be covered at a time with the same hardware; thus the facility would have to be missionized. The obvious trade-off for receiver design is frequency bandwidth versus sample bandwidth. Particularly in the crowded bands below 10 GHz, a very narrow sample is almost a prerequisite. A narrow sample bandwidth will also increase the receiver sensitivity for a given signal to noise ratio. Halving the IF passband gives an extra 3 dB in power sensitivity, but narrower passbands imply more samples and a longer time to cover the band.

Some obviously important signal parameters of interest to obtain are:
- Location of emitters on the earth’s surface
- Frequency and polarization of emitters
- Signal strength of emitters
- Time at which emission was detected

Location data is determined either from antenna beam position for a narrow-beam antenna system or as an output from the DF receiver system. This raw data, angle-of-arrival information, is combined with data on atmospheric signal refraction, spacecraft attitude data, and location data to compute the location of the emitter on the earth’s surface.
Signal strength is the basic parameter measured by the receiver. This raw data, a video amplitude, will be converted to a receiver input signal strength based on the calibration of the receiver. This input signal strength will be corrected to represent transmitted EIRP by subtracting the receiver antenna gain and adding the path loss and any other known atmospheric losses. The received signal strength data can also be used to evaluate atmospheric propagation effects on signal strength such as rainfall attenuation. This would be accomplished by using a calibrated emitter whose EIRP is known.

The various data corrections discussed in the above paragraphs could be performed either in the spacecraft or in the ground station. The trade-off would involve the accessibility of the needed spacecraft data to the ground station, availability of processing power on-board, data rates, etc.

B. Laser Experimentation

Spacelab affords an excellent test bed to develop the technology for space-to-ground, high capacity (greater than 300 MBPS) laser communications; and, if the opportunity is available, for space-to-space laser communications. Definition activities have been started by the NASA-GSFC for a 10.6 micron, CO$_2$ laser transceiver having a capability to transmit greater than 300 MBPS from a low altitude spacecraft (Spacelab) to a ground station or to another satellite.

The need for high capacity data relay links in the near future is evident when one examines the data output of some of the planned instruments being considered for the Earth Observatory Satellites.

A synthetic aperture radar produces 200 MBPS, a high resolution pointable imager produced 120 MBPS, the thematic mapper puts out 100 MBPS. Spacelab alone, with its potential experiment weight capability of 4-11,000 kilograms may well produce 500-1,000 MBPS, depending upon the particular complement of instruments on a flight. Laser communications are one technology, millimeter waves are another, to provide the flow of these data to ground stations or to future relay satellites.

The Spacelab laser transceiver, shown in Figure 2, has a transmitter output power of 700 milliwatts and weighs about 55 kg. It will permit two way, simultaneous data relay from space-to-ground and ground-to-space. The experiments to be performed include: laser acquisition on the ground and in the Spacelab, technical aspects of equipment performance and reliability, atmospheric propagation experiments and finally communications demonstration tests.
In the same time period as Spacelab, NASA and the Air Force (AF) are planning the flight of an automated spacecraft containing a CO$_2$ laser transceiver (provided by NASA) and a Nd: YAG laser transmitter (provided by the AF). The spacecraft is planned to be placed into a 12-hour elliptical orbit with an apogee of 39,000 Km and a perigee of 1670 Km. The laser equipment planned for Spacelab-to-earth tests is capable of acquiring and transmitting data to this 12-hour orbit spacecraft. What will be required is that Spacelab perform a 180° roll such that the laser telescope is pointing skyward.

C. Bandwidth Compressive Modulation

The Jet Propulsion Laboratory is examining a Bandwidth Compressive Modulation Shuttle Experiment (BCMSE) to demonstrate technology for a very high rate digital space communication link. This experiment will evaluate bandwidth compression ratios of up to 6:1 by use of multiple phase-and-amplitude modulation techniques.

This experiment is motivated by spectral congestion, primarily in frequencies below 6 GHz. It has three major objectives. First is the collection of operational communication link performance information about the acquisition and tracking ability and link error rates of the bandwidth compressive modulation (BCM) system. The second is collection of statistical data on propagation phenomena degradation of this form of modulation at various frequencies in the 0.4 to 30 GHz range. The third is an operational demonstration with user experiments utilizing the unique capabilities of the BCM system.

BCM is an attempt to alleviate congestion of digital links not by new frequency allocations or by frequency re-use but by using the allocated spectrum in a more efficient manner. This form of modulation packs multiple numbers of bits of information into each transmitted signal by forcing the transmitter carrier phase and amplitude to take on one of a number of possible values during each signaling interval. For example, if sixty-four possible phase-amplitude combinations are permitted in each interval, then six bits ($\log_2 64 = 6$) of information can be transmitted in each signal.

The primary penalties paid by BCM are increased transmitter power requirements, increased implementation costs (due to more sophisticated transmitters and receivers), and increased sensitivity to media and noise. Although it might seem incongruous to consider using power to save bandwidth on space communication

**The term “compression ratio” is not used here in the usual sense as applied to digital data streams. Redundancy is not removed from the data. Rather, blocks of unprocessed data bits modulate the carrier amplitude and phase to permit transmission at a reduced signaling rate.
systems, it is in fact plausible today. In deep space applications, bandwidth is still usually expanded in order to reduce power requirements. This is because of low data rate requirements, a generous frequency allocation, and severe weight and power constraints. Near-Earth communications on the other hand, face a relaxed power constraint and an increasing spectral squeeze. This easing of the power bind is due to advances in launch vehicle technology and space hardware, which permit larger space packages with higher gain-power products. Thus, this increased power capability in near-space permits utilization of the BCM to reduce spectral congestion. BCM involves simultaneous modulation of a microwave carrier with multiple phases and amplitudes at high data rates. The transmitter must preserve these phase-amplitude pairs during final amplification. The receiver must be capable of handling these broad power variations at high data rate (the power in adjacent symbols may differ by as much as 17 dB at a 6:1 compression ratio), while distinguishing simultaneously which of the multiplicity of possible phases and amplitudes was received. Additionally, the receiver must be synchronized and tracked in time, frequency, phase, and amplitude, and the bit stream must be processed prior to signal generation in the transmitter and after signal detection in the receiver.

BCM can be analyzed in the laboratory, but final assessment of the technology and its performance for space communication requires space flights to determine performance under actual operating conditions. The Shuttle Spacelab provides a flexible means for conducting the assessment. The sensitivity of this form of communication to propagation phenomena and noise makes this space flight test essential, since the analyses, simulations, and other tests may not adequately reflect the sensitivity to time-varying operating conditions.

This experiment will establish a direct communication link between selected ground stations and the Shuttle, using a separate pallet-mounted antenna and special equipment within the Spacelab. The Shuttle communication system will not be required for the experiment. The experiment will be conducted over a succession of several missions. It will require establishing one-way links from the Shuttle to ground stations on early flights (and two-way links between ground stations via a transponder in the Spacelab on later flights).

Specific types of test data will be transmitted for the purpose of evaluating operational performance, measuring error characteristics, and assessing effects of propagation. Selected microwave frequencies will be examined. Use of multiple flights will permit repeated transmission under a diversity of weather patterns, restrict the equipment frequency range required in any one flight, and allow evolution of the experiment from one-way links to two-way links.
The links will use various modulation forms including continuous CW, binary phase shift keying, multiple phase shift keying, and multiple amplitude-and-phase shift keying for calibration and evaluation. The flight equipment will be laboratory type equipment that can be readily configured and adjusted by an astronaut for each modulation/demodulation technique. This equipment will include modulators, transmitters, and control, support, and instrumentation equipment, all housed within the laboratory, and an antenna mounted on the pallet. Hardware at the ground stations will be required to acquire and track the signal parameters (timing, phase, and amplitude), the received signals, and reduce and interpret the data recovered.

Large Deployable Communications Antenna

There are numerous space applications disciplines that would benefit from large aperture spaceborne antennas, (one is shown in Figure 3). These include: radio frequency interference measurements and detection; radiometers, for determining terrestrial and ocean surface temperature measurements; planetary bound spacecraft or landers could transmit greater amounts of data to ground; broadcasting to small, remote, fixed or mobile terminals; and use by future generation tracking and data relay satellites.

Common to all of these applications is the need to deploy the antenna from the automated spacecraft, since the required antenna diameter is significantly larger than current and projected launch vehicles, including the Space Shuttle. The ATS-6 demonstrated the deployment of a 9.15 meter diameter parabolic dish. Future space applications needs may require antenna diameters as great as 100 meters.

The Shuttle’s Spacelab affords the spacecraft manager or R & D engineer the opportunity to develop and demonstrate improved antennas and new deployment concepts. Ground tests of deployable antennas are not completely valid since the zero gravity effects cannot be taken into account. Additionally, many environmental and performance tests cannot be performed unless prohibitively expensive, new, large size facilities are constructed. Spacelab tests provide data in as close to the actual operating environment as possible.

Mechanical tests of the antenna would include the stresses in the antenna ribs during and after deployment, the degree of hysteresis, the surface accuracies as a function of time in orbit, and the general effects of the space environment on the structure.

An additional mechanical feature that would be incorporated for Spacelab experimentation, is an antenna redeployment feature. This would be mechanically actuated, with the astronaut assisting via an EVA mission if required. This feature will require detailed design study. The antenna return to earth will permit laboratory examination of its days in space, and permit its reuse on future Spacelab missions for other discipline applications.
presence of astronauts provides special capabilities not available with automated spacecraft. Their direct visual observation can provide qualitative and quantitative data regarding antenna deployment not available through practical automatic telemetry. For large multielement arrays, astronauts could be used for the assemble process. In addition, astronauts could manually change the antenna feeds on some antennas providing more experiment data. This would allow the antenna to be operated over a wide-frequency range without the necessity of a single multi-purpose feed, a costly and performance compromising approach.

Finally, the reuse shuttle capability would allow repeats of demonstration experiments for a variety of applications. By such experiments the benefits of large apertures to each application could be demonstrated before a commitment to a costly design decision would have to be made.

Conclusions. Based upon the results of numerous studies and meetings of communications experts in the US and Europe the following may be said about the usefulness of Spacelab:

I. It can be expected that Spacelab will reduce the time, risk and cost for conducting some communications experiments and developing the related space technology.

II. A useful application of Spacelab to communication will be when performing experiments/technology developments that involve humans in a necessary and relevant manner to increase the useful data output and decrease the instrument complexity and cost.

III. Early implementation of longer than 7 days (30 days or greater) Spacelab missions are desired. This added time is desired to obtain more statistical day for propagation studies and performance/operations data.

IV. US industry dealing in space communications R&D and operational spacecraft should examine the advantages Spacelab testing can provide for future technology developments.

References:


5. A Shuttle/Spacelab RF Environment Survey System, by R. Taylor, etc. presented at IEEE National Telecommunications Conference, 12/74 San Diego, California.


CO₂ LASER TRANSCEIVER

FIGURE 2

LARGE DEPLOYABLE ANTENNA SHUTTLE EXPERIMENT

FIGURE 3