A SPACEBORNE RECEIVER FOR MEASURING ELECTROMAGNETIC FIELD INTENSITY[1]

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Summary At the present time, considerable interference with communications to and from spacecraft has been experienced. Consequently, the need for determining the extent of this interference was indicated. NASA contracted AIL to design and build a very accurately controlled receiver to monitor the electromagnetic radiations in both existing and projected space communication bands. Based on analysis of the existing and projected space communication bands, 108 to 174 MHz, 240 to 478 MHz, and 1535 to 1665 MHz were covered. The receiver achieves accurate control via a digitally tuned synthesizer and a wide range of digital control including frequency band coverage and gain control selection. Digital memory was provided to store 16 separate digital command instructions which can be programmed via a command data link. The receiver provides for transmission to the ground of both a predetection signal and signals in digital format, which in turn, were provided by sampling and analog-to-digital conversions.

Introduction Space telecommunication systems are being designed without engineering information on the nature of the electromagnetic environment. Because of this deficiency, NASA has experienced unexpected rf interference problems that have impaired operations. The increasing use of the spectrum will increase the likelihood of future disaster as long as communication engineers are forced to operate blind.

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Within the past ten years there has been an increased emphasis within the U.S. Government on frequency management problems. In 1966, the Telecommunication Science Panel of Commerce Technical Advisory Board concluded, after an analysis of the electromagnetic spectrum utilization problem, that there were not adequate technical programs aimed at improvement of the overall effectiveness of the utilization of the spectrum. This panel recommended at that time that research organization and programs be developed to provide the Director of Telecommunications Management, The Federal Communications Commission, the Department of State, and all other government, industrial, and academic institutions having an interest in telecommunications with the technical information and analyses necessary to provide a valid basis for judgements which affect the overall effectiveness of the use of the spectrum. In December 1966, the Director of the Office of Telecommunications Management (now the Office of Telecommunications policy), recognizing the need for more technical programs designed to improve the overall effectiveness of spectrum utilization, asked the National Aeronautics and Space Administration to undertake the design of experiments to measure factors influencing frequency utilization and sharing between communication satellite systems and terrestrial radio relay systems. NASA accepted and established what is now the communication link characterization program which included contracting AIL to design and build this receiver.

The purpose of this paper is to describe in some detail the design of this receiver, with particular emphasis on its performance requirements along with the rationale for the selection of the frequency bands being covered.

In general, the approach was to provide a highly accurate and flexible receiver which, via ground control, could monitor the electromagnetic radiations in three selected bands. The monitored data in both predetected and digital forms would be telemetered to the ground via normal data links. In the area of accuracy and flexibility, the receiver is designed to be capable of being programmed to scan precise predetermined portions of the spectrum with a variety of selectable bandwidths and types of detectors. as well as the basic predetection signal. In order to effect an accurate measurement of the signal strengths over a wide dynamic range, programmable gain settings and automatic gain control capability are provided.

Rationale for Selection of Frequency Bands Only those frequency bands which are of immediate concern to NASA have been chosen for this receiver. These are at VHF, UHF, and L-band.

There is intensive NASA interest in the VHF band because it is used for spacecraft command and data transmission assignments are proposed for 136 to 138 and 148 to 150 MHz.

The 148 to 162 MHz band is assigned to railroad, maritime, highway maintenance, taxicab, and police radio services. The bands 148 to 150 and 162 to 170 MHz are allocated for space telecommunication links. However, heavy foreign utilization from 152 to 170 MHz for radar and surveillance restricts the use of this band.

The fm broadcast service occupies the band from 88 to 108 MHz; television channels 5 and 6 occupy the band from 76 to 88 MHz; radio astronomy and aeronautical radio navigation occupy the band from 72 to 76 MHz; television channels 2, 3, and 4 occupy the band from 54 to 72 MHz; amateur radio occupies the band from 50 to 54 MHz. Consequently, it is impractical to use the frequency region below 108 MHz for space telecommunications and 108 MHz was selected as the lowest frequency of measurement for this experiment.

There is little NASA interest in examining the frequency spectrum from 174 to 240 MHz. Practical use of this band for space telecommunication links is limited by the VHF television service (channels 7 to 13) whichoccupy the band 174 to 216 MHz, and aeronautical and military radar which occupy the band from 216 to 240 MHz.

Meteorological satellites and data collection platforms operate in the band from 400 to 410 MHz. As a result of the 1971 WARC-ST, the bands 240 to 328.6 and 335.4 to 399.9 MHz are to be shared by land mobile and satellite services. Additionally, aeronautical and military communication systems operate in the 225 to 400 MHz band.

UHF television channels 14 through 83 occupy the region between 470 and 960 MHz, air traffic control radar occupies the band from 960 to 1215 MHz, and air surveillance radar occupies the band from 1215 to 1400 MHz. The band from 1400 to 1540 is allocated to aeronautical telemetry.

The portion of the UHF band of interest to NASA thus extends from 240 to 470 MHz.

The frequency band from 1558.5 to 1636.5 MHz is reserved on a world-wide basis for the use and development of airborne electronic aids to navigation and any directly associated ground-based or satellite-borne facilities. This band is also allocated to the aeronautical mobile service for the use and development of systems using space radio communication techniques. Such use and development is subject to agreement and coordination among administrations concerned and those having services operating in accordance with the WARC which may be affected. The use of this band is also allocated to transmissions from space to earth stations in the maritime mobile-satellite service for communication and/or radio determination purposes. Transmissions from coast stations directly to ship stations, or between ship stations, are also authorized when such transmissions are used to extend or supplement the satellite-to-ship links.

There are several frequency bands above 1665 MHz that are of interest for space communications. However, examination of these bands will not be made by this experiment to avoid excessive cost and complexity for this first experiment.

Additional information on frequency allocations is given in Table 1. As was noted, there have been communication problems in the spacecraft resulting from interference. Table 2 documents some specific examples of interference.

Performance Characteristics In order to achieve the basic objective of determining the rf field strength as a function of frequency and location, the receiver should provide three basic measurements: frequency of the received signal, signal amplitude, and time.

Since it is important to correlate signals, an accurate frequency measurement is required. Consequently, the basic stability (absolute accuracy) of the frequency determining elements shall be 5 parts in 106 and the capability of resolution is as fine as 25 kHz. However, in order to process wider spectrum signals, 200-kHz resolution is provided.

High accuracy in the measurement of signal amplitude is also vital. Consequently, the receiver provides a basic accuracy of better than 3 dB. Of course, the absolute measurement of signal strength is dependent on accurate determination of the receiving antenna performance and calibration of the overall system including the telemetering downlink. Table 3 lists the minimum detectable ground emitter power levels and Table 4 is a summary of the receiver characteristics.

Although a time measurement is not provided in the receiver, time measurements to the required accuracy for correlation purposes is provided on the ground. This is practical because all data is transmitted in real or near real time.

Receiver Design The receiver is more comp lex than a typical spacecraft receiver. It is programmable and remotely operable via the spacecraft command system. It has a built-in memory and a separate power supply which permits memory retention without energizing the entire receiver. A telemetry f ormatter in the receiver produces a PCM serial bit stream for telemetering the receiver signal data. The frame sync pattern, housekeeping status, and tuned frequency identifications are included in each PCM frame. The serial bit stream modulates a subcarrier oscillator. Concurrently, a portion of the tuned rf spectrum is translated in frequency to 260 kHz. This undetected (predetection signal) is combined with the subcarrier oscillator signal to form the receiver output.

Figure 1 is a simplified block diagram of the receiver and Figure 2 is a photograph of the receiver with its covers removed. The synthesizer is the large assembly to the left. The digital portion, consisting of nine printed circuit boards, is toward the right. The bottom section is the chassis which also houses the rf portion and the power supplies.

Table 1. Principal Frequency Allocation/Usage for U.S. (Region 2) Bands Within Selected Frequency Bands

Frequency Rf Interference Receiver (MHz)	Subband (MHz)		Usage
Band A (108 to 174)	108	to 117.975	Aeronautical Radionav
	117.975	to 132	Aeronautical Mobile
	132	to 136	Aero-Comm incl fixed and mobile
	136	to 137	Space Research (Space-Earth)
	137	to 138	Met Satellite, Space Ops/Research
	138	to 143.65	Space Research, Military Aircomm
	143.65	to 144	Space Research, Military Aircomm
	144	to 148	Amateur Radio
	148	to 149.9	Fixed and Mobile
	149.9	to 150.05	Radionavigation-Satellite
	150.05	to 157.3125	Misc Fixed and Mobile
	157.3125	to 157.4175	Satellite Maritime Safety (Ship-Sat)
	157.4175	to 161.9125	Misc Fixed and Mobile
	161.9125	to 162.0125	Satellite Maritime Safety (Sat-Ship)
	162.0125	to 174	Misc Fixed and Mobile
Band B (240 to 473)	240	to 399.9	Military Aircraft/Marit Comm
	399.9	to 400.05	Radionavigation Satellite
	400.05	to 400.15	Standard Frequency Satellite
	400.15	to 406	Met Aids and Space Ops
	406	to 406.1	Mobile Satellite-Emerg Posit Loc
	406.1	to 420	Government Fixed and Mobile
	420	to 450	Radar DOT/FAA & DOD
	450	to 460	Land Mobile/Public Safety
	460	to 470	Met Satellite (Space-Earth) and Land Fixed/Mobile
	470	to 478	Broadcasting-UHF TV
Band C (1535 to 1665)	1535.1	to 1558.5	Maritime/Aeronaut
	1558.5	to 1666	Aero Radionav Marit/Aero Mobile Sat

Table 2. Examples of Interference

Spacecraft	Description of Interference
NIMBUS	The IRLS experiment lost about 2 out of 3 interrogations over the U. S. and Europe due to interference
OAO-2	The command memory could not be accessed due to interference. This caused operational difficulties
OAO-5, OSO-6, OGO-6 NIMBUS-3	The spacecraft status changed unexpectedly due to interference affecting the command system
IMP-4	TM data was degraded due to interference
OSO-5	TM data was degraded due to interference

ATS-3	The OPLE transponder signal dropped out and the platform receiver saturated due to interference
NASA STADAN	Operation affected by interference
EOLE	The experiment could not be performed in some portions of the northern hemisphere because of high UHF field intensities

Table 3. Minimum Detectable Ground Emitter Power Levels

Band	Frequency
A	108 to 174 MHz
B	240 to 478 MHz
C	1535 to 1665 MHz

Tuning increments = 25, 50, 100, 200 kHz
Stepping rates = 400 steps/s to 1 step/110 min
Predetection bandwidths = 25 and 200 kHz
Nominal noise figure = 5 dB (band A), 5 dB (band B), 7.7 dB (band C)
Nominal a-m sensitivity (10 dB signal-to-noise ratio)

Band	25 kHz	200 kHz
A	-115 dBm	-106 dBm
B	-115 dBm	-106 dBm
C	-112.3 dBm	-103.3 dBm

Nominal f m quieting (I 5 dB signal-to-noise ratio)

Band	25 kHz
A	-115 dBm
B	-115 dBm
C	-112.3 dBm

Dynamic range - thermal noise to -60 dBm
Sensitivity to spurious and image signals = -60 dBm
Automatic gain control time constants = 0.5, 5.0, 50, 500 ms
Manual automatic gain control settings = -120, -110, -100, -90, -80, -70, -60 dBm

Command storage = 16 to 56 bit command words, each word contains command number, operating band, start frequency, stop frequency, frequency step size, stepping rate, and predetection converter bandwidth.

Table 4. Summary of Receiver Characteristics

Frequency (MHz)	Ground Emitter EIRP in dBW (With Emitter at Edge of Beam): Antenna Beam Width = 108° BW = 25 kHz	Antenna Beam Width = 108° BW = 200 kHz	Antenna Beam Width = 90° BW = 25 kHz	Antenna Beam Width = 90° BW = 200 kHz
108	6.5	15.5	-4.3	4.7
141	8.8	17.8	-2.0	7.0
174	10.6	19.6	-0.2	8.8
380	17.4	26.4	6.6	15.6
425	18.4	27.4	7.6	16.6
470	19.2	28.2	8.4	17.4
1540	30.6	39.6	19.8	28.8
1600	30.9	39.9	20.1	29.1
1660	31.2	40.2	20.4	29.4
(With Emitter Directly Beneath Spacecraft)				
108	-6.5	2.5	-11.6	- 2.6
141	-4.2	4.8	- 9.3	- 0.3
174	-2.4	6.6	- 7.5	+ 1.5
380	4.4	13.4	- 0.7	8.3
425	5.4	14.4	+ 0.3	9.3
470	6.2	15.2	1.1	10.1
1540	17.6	26.6	12.5	21.5
1600	17.9	26.9	12.8	21.8
1660	18.2	27.2	13.1	22.1

Signal-to-Noise Ratio = 10 dB (a-m), 15 dB (fm)
Antenna Gain at 108° = 0 dB, at 90° = 5.1 dB
Slant Range at 108° = 4116 km, at 90° = 2166 km
Overhead Range = 1464 km
Δ Path Loss, Edge - Beneath = 10 dB at 108°, 4.3 dB at 90°

Carrier-to-Noise Ratio dB-Hz	= +79.0 dB
10 $\log_{10}$ (200 kHz)	= -53.0 dB
Overall Carrier-to-Noise Ratio	+26.0 dB
Carrier-to-Noise Ratio Threshold	-10.0 dB
Carrier-to-Noise Ratio Margin	16.0 dB

The receiver weighs approximately 38 lb and consumes about 40 W while fully active and about 9 W when only the memory and its separate power supply are active.

The receiver consists of three major portions: the rf , the synthesizer, and the digital logic. The rf portion consists of filtering, mixers, and switches required to facilitate operation over the three bands with two selectable final i-f bandwidths and selectable automatic and manual gain controls. Quadruple conversion is used in the low bands, bands A and B, whereas triple conversion is used in the high band, band C. The output of the receiver is in two basic forms: predetected and digitized detected. In the latter case, either a-m or discriminator detection is provided. Under automatic gain control operation, four selectable time constants are provided.

The synthesizer provides all local oscillator outputs for all the conversions, fixed tuned as well as step tuned. In the case of the step tuning, four stepping increments and twelve stepping rates are provided. The synthesizer local oscillator outputs are all of high purity and stability as each is filtered and locked to crystal-controlled oscillators. The synthesizer is, of course, digitally controlled.

The digital logic portion contains the memory for storing 16 commands and the distribution circuits for each of the various controls, such as, band selection, frequency range selection, automatic gain control time constant selection, manual gain setting selection, and so on. In addition, the logic is provided to accumulate and format all of the digital data including the basic signal data, monitoring points, and housekeeping data. The digital portion also includes the necessary analog-to-digital conversions and the circuits that combine the digital and predetection signals into a form compatible with the downlink transmitter.

The control f lexibility of the receiver is such that any combination of scan rate, step size, bands, and frequency sector in each band can be programmed via the commands. This permits very thorough examination of frequencies of prime interest and/or cursory examination of frequencies of less importance.

Conclusion Although the receiver design was completed, fabricated, and tested on the grounds that it has not been flown to date, its design generally met the basic objectives and performance characteristics. Thefollowingliststheoutputplotsanddocumentationthatcanbe provided with appropriate data reduction and analysis.

a. Peak power density per unit bandwidth
b. Average power density per unit bandwidth
c. Peak/average power density ratios
d. Percent occupancy statistics of received signals
e. Temporal statistics (to a limited extent; time of day, time of week)

f. Regional mapping (to a limited extent)
g. Measured versus expected values of received spectral power density levels
h. Panoramic plots of power density versus frequency for selected bands

Finally, the data collected and processed will be directed toward reports and studies with the following applications.

a. Develop operational procedures for improved satellite data-collection efficiency
b. Select optimum modulation schemes and/or coding techniques
c. Improve space-terrestrial services which share allocations
d. Improve data communications scheduling
e. Monitor and control emitters
f. Perform tradeoff studies for followon, dedicated missions
g. Design protection filters or antijam measures
h. Update characteristics for general use of scientific/ communications communities
i. Collect information in the national interest

Reference B. W. Reich, C. P. Smith, J. Eckerman, E. A. Wolff, M. Cornell, and J. Deskevich, "An Electromagnetic Field Intensity Experiment for an ITOS-D Configuration Spacecraft Report," Goddard Space Flight Center, Greenbelt, Maryland, June 1972.

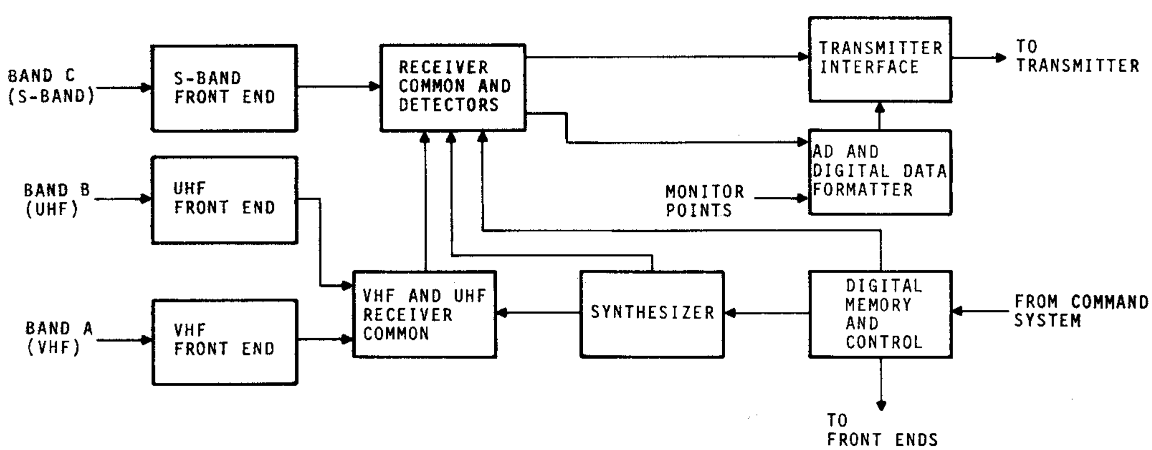

Figure 1. RFI Receiver, Simplified Block Diagram

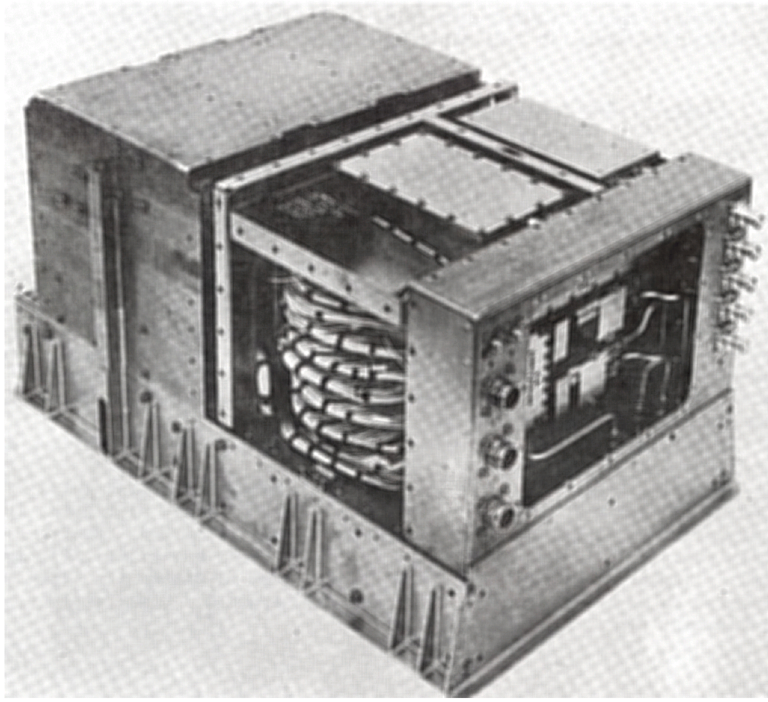

Figure 2. Photograph of the Receiver