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ROCSAT-1 Telecommunication Experiments

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Abstract

This paper addresses a telecommunication payload project approved by the R.O.C. NSPO's ROCSAT-1 space program. This project will enable several innovative experiments via the low-earth-orbit satellite ROCSAT-1, including multipath fading channel characterization, ionospheric scintillation measurement, real-time voice communications, and CDMA data communications. A unified L/S-band transponder payload is proposed for conducting these experiments in an efficient way. The results of these experiments would provide the evolving mobile communication communities with fruitful information.

1 Introduction

Due to the increasing demands of universal personal communications services, there has recently emerged the idea of using multiple low-earth-orbiting (LEO) satellites to provide additional mobile voice and data communications services, supplementing the evolving terrestrial mobile communication services. To carry out this idea, several projects, for examples, Iridium, Odysseys, and Globalstar, have been proposed by Motorola, TRW, and Loral ([1], [2]), respectively. The operating quality of these proposed communication systems will be the primary subject for communications through highly dynamic environments, precisely the multipath fading channel resulting from the surface scattering effect. Since the relative speed between LEO satellites and ground terminals is extremely high and fast time-varying, a highly nonstationary fading channel that is fairly different from any existing multipath fading channel model, is expected. Due to the unique environment in Taiwan, fade characteristics can be quite different from that of other major cities in the world (for example, Chicago).

Recently, a long range space program, proposed by the National Space Program Office (NSPO) of the Republic of China (R.O.C.), has been approved by the Executive Yuan of the R.O.C. government. Within the program, the NSPO schedules to launch in 1997 her first (low-earth-orbiting) satellite, ROCSAT-1, with a designed life of about four years to perform several science and telecommunications experiments. A mixture of circular and elliptic orbits at 35° inclination have been suggested to accomplish the mission. On board ROCSAT-1, a telecommunication payload has been allocated to perform several ROCSAT-1 Telecommunication Experiments ([3], [4]). The major intent of this telecommunication payload is to evaluate the aforementioned cellular LEO satellite projects and to acquire adequate channel characteristic information for a better system design in Taiwan. Toward these ends, we have proposed four experiments, namely Fading Channel Characterization, Ionospheric Scintillation Measurement, Real-Time Voice Communications, and CDMA Data Communications. The purposes of the proposed experiments are:

1. To characterize the multipath fading chan-

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nels of the L- and S- band LEO-satellite-based cellular voice and data communication systems. The fade characteristics may be unique for various specific environments in Taiwan.

2. To measure the L- and S- band ionospheric scintillation in Taiwan area simultaneously, and to further define the density and size distributions of the irregularities that are responsible for the scintillation.

3. To evaluate the end-to-end LEO personal CDMA space communication system performance by measuring the bit error rate (BER) and voice quality. Various vocoder techniques and rates will be employed for the experiments. Compatibility with terrestrial cellular CDMA systems will also be evaluated.

4. To perform the LEO CDMA space telecommunication using on-board store and forward processor. Global data collection, paging, and message broadcasting experiments will be conducted.

This payload project is currently under feasibility study. We shall give more details on the proposed experiments and the conceptual design of the proposed payload in what follow.

2 Experiment Description

2.1 Fading Channel Characterization

The measurement system is based on a spread spectrum communication technique. The approach is to transmit pseudo-noise (PN) sequence modulated S- and L- band carriers from a LEO satellite and observe channels' complex impulse response by despreading the received signals with a local PN replica. Basically, this system follows the approach proposed by [5] for cellular land mobile channel measurement. The high dynamics LEO environment, however, calls for extra efforts to remove the Doppler frequency and differential Doppler that are embedded in the received signal but undesirable to the channel characterization. For this reason a dual-channel architecture (synchronous and measurement channels) for the ground measurement system is necessitated. The synchronous channel receives downlink beacon signal by use of a L-band tracking antenna with 26 dBi gain. It is responsible for tracking the variations of those variables induced by the satellite orbit dynamic (i.e., Doppler, differential Doppler, jerk, code Doppler) and acquiring the transmitted test signal (i.e., carrier frequency and PN code phase). This information is needed so that the "clean" channel responses free of orbit dynamic effects at desired delays can be obtained at the measurement channel.

Experiments will be conducted for various ground environment modes, including (1) suburban and rural, (2) vegetation, (3) marine, (4) hilly, and (5) metropolitan. These selected environments contain both typical mobile communication environments and special geographic features and terrains in Taiwan. The PN code rate will be 10 Mcps which yields a multipath resolution of 100 ns. For a code length of 8191 chips, the duration of the measured delay profiles is equal to 0.8191 ms. Table 1 gives the S-band power budget for the multipath resolution, in which the fade margin is fixed at least 15 dB. The EIRP at 10 degree elevation angle on the ground is 10 dBW for both S- and L- band measurement signals. The expected outputs of the whole experiment will include (i) an exhaustive collection of power delay profiles as well as delay Doppler power profiles for typical geographical features and terrains, (ii) the corresponding statistical description of path delays, amplitudes, and phases for all the significant paths, and (iii) relevant statistical quantities, such as rms delay and Doppler spreads, -3 dB and -7 dB profile widths, etc.. The outputs will provide communication system engineers with a thorough statistical description of a typical mobile LEO-satellite multipath channel.

2.2 Ionospheric Scintillation Measurement

Taiwan is in the equatorial anomaly crest region where the ionosphere quite often exhibits rather irregular behavior and GHz scintillation has been observed. Since the LEO satellite can scan a large area of about several thousands of kilometers wide and provide more spatial information than the geostationary satellite, our experiment is meaningful and will contribute significantly to the global morphology of ionospheric scintillations.

L- and S- band beacon signals with EIRP of 3 dBW at EOL will be transmitted downlink simultaneously. Both amplitudes and phases will be sampled with a rate of 1000 samples/second, and recorded at the receiver. This is accomplished by using the S-band beacon as a reference to calibrate the phase of the L-band beacon. In order to maximize the link availability, circular polarization with axial rate lower than 5 dB is utilized. Dynamic range for amplitude is 16 dB with a resolution of 0.5 dB. The resolution for phase measurement is 5°. With the recorded data, we shall obtain useful physical quantities, such as correlation at the different frequencies, time instants, and positions, scintillation index, frequency power spectra for the log-amplitude and the phase, etc.. By using the Rytov solution of scintillation theory, several physical parameters of the ionospheric irregularities, such as turbulence strength, spectral index, etc., can then be derived. These results will be of much importance in understanding the structure and dynamics of the F-region nighttime irregularities. Moreover, they can also be correlatively compared with the VHF radar data, the total electron content data, in-situ measurements on board ROCSAT-1, and the spread-F data, to give us a deeper understanding of the ionosphere in Taiwan area.

2.3 Real-Time Voice Communications

The experiment system consists of a L-band transmitter, bentpipe transponder, and S-band receiver (as shown in Fig. 1). The programmable data pattern is used for BER measurement and error statistics analysis, while the voice input is also allowed for demonstration and evaluation of voice quality. Both standard and improved CELP (Code Exited Linear Predict Code) techniques at data rates of 9600, 4800, and 2400 bps are adopted in vocoder realization. A (2,1,7) convolutional code and corresponding soft-decision Viterbi decoder are employed for a 5 dB of BER improvement. The encoded symbol rate is fixed by 19.2 Kbps; henceforth, repetition codes of different code rates are employed prior to convolutional encoding. To reduce burst error effect, a block interleaver is used to span the encoded sequence over 30 ms. The interleaved sequence is then modulated by the DS/BPSK modulator. The PN period is programmable (ranging from R6 to R13) at two chip rates 1.23 and 4.92 Mcps for evaluation of the underlined multipath fading effect. In order to resolve severe Doppler effects due to ROCSAT-1 motion, a pre-compensation/post-correction approach is adopted, which requires a tracking antenna of gain 26 dB at the receiver. The power budget for this experiment is given in Table 2. It is shown that 13 dBW of transmission power is needed to maintain a BER of 10^{-4}.

2.4 CDMA Data Communications

Three sub-experiments will be conducted, namely global data collection, global paging, and store-and-forward message transmission. CDMA scheme will be adopted as the access scheme.

The data collection experiment consists of a small number (8 to 12) of transmit only remote terminals and a receive only Hub terminal, for the collection of meteorological, oceanographic, hydrological, flood control, and seismic data. Though the basic packet data rate of 4.8 Kbps is assumed and the sampling rate will be no more than 20 Hz, a wide range of channel, data formatting and burst architecture, burst ranges, and access techniques will be possible for testing.

The global paging is a receive only experiment. It is intended to answer several important unsolved issues for future satellite handheld personal communications, such as phase noise effects, polarization effects, polarization or antenna diversity (inside buildings), interleaving, and FEC coding for low bit-rate transmission and reception. Since the paging signal is expected to be low bit rate to provide additional link margin for building penetration, this experiment will use S band small antenna to verify the reception phenomena at various floor levels and depths within a building, inside a moving vehicle, with the receiver carried on the person or inside a briefcase.

Since a LEO satellite is in a view for only a few minutes, store-and-forward message transmission will exercise an important feature for LEO satellite commuincations. A remote terminal may send a non-real-time message to the satellite stored and re-transmitted when the satellite passing through the receiving terminal. CDMA technology will be used for message transmission and acquisition. The proposed store-and-forward message experiment will be used to evaluate the feasibility and integrity of such a communication system. Statistics on the message integrity, in terms of bit error rate, packet error rate and miss and false acquisition probabilities, will be obtained for various reception conditions.

3 Payload Description

A unified L/S-band transponder payload with components that have been flown on other satellite programs or are available in flight qualifiable form is proposed for this project. This payload consists of L/S-band antennas, an L/S-band bentpipe transponder, an L-band transmitter, and a baseband store-and-forward CDMA processor. Since ROCSAT-1 is a 1000 lbs class satellite with only about 400 W of total electrical power available for six different payloads, this payload will utilize a compact L- to S- band transponder with about 43 W of DC power consumption within Taiwan area, and about 8 kg of weight. The nominal DC voltage from satellite bus is 28 V. In order to minimize payload weight and power, mechanical tracking antenna is not recommended. Shaped antenna pattern to compensate for the free path loss difference within the coverage area is used instead. The spacecraft antenna will have beamwidth of about 120°.

The proposed payload is a space-qualified solid-state transmitter/receiver with L-band uplink and L- and S- band downlink, whose conceptual design is illustrated in Fig. 2. This payload is designed to provide the flexibility of dual mode operation at L- and S- bands. In one mode, the bypass switches may be exercised to make the payload as a transponder for transmission of real-time voice. In the other mode, it serves as either a store-and-forward CDMA regenerative transponder or a PN sequence transmitter. In both modes, the L- and S- band coherent beacon signals are always transmitted for scintillation measurement experiment. The payload is operated by an on-board computer unit interfaced to the satellite command and data handling subsystem, which also records the payload housekeeping data.

4 Conclusion

A L/S-band transponder payload has been proposed for the R.O.C. NSPO's ROCSAT-1 program, and will enable the following innovative experiments via the LEO satellite:

- Multipath fading channel characterization
- Ionospheric scintillation measurement
- Real-time voice communications
- CDMA data communications (store-and-forward message transmission, global data collection, and global paging)

These proposed experiments would promote a broad based participations by the scientific and technical communities as well as local industries in the R.O.C.. They would also stimulate and enhance the earth terminal technology readiness in Taiwan for competition in the emerging market place of digital wireless and personal communications. In particular, the measured LEO multipath fading channel characteristic and evaluation of the LEO personal CDMA space systems would provide the evolving mobile communication communities with fruitful information.

References

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[4] "L/S-Band Personal Communications Payload," NSPO ROCSAT-1 payload proposed by Telecommunication Laboratories and COMSAT Laboratories.

[5] D.C. Cox, "Delay-Doppler characteristics of multipath propagation at 910 MHz in a suburban mobile radio environment," *IEEE Trans. Antennas Propagat.*, vol. AP-20, pp. 625-635, Sept. 1972.

	(S-band, EOL budget)	NOMINAL	TOL +/-
* 1	PAYLOAD SGL EIRP, DBW (5W, 3dB)	10.00	0.00
* 2	POINTING LOSS, DB	0.00	
* 3	PATH LOSS, DB	166.42	
	3a RANGE, KM	2000.00	
	3b FREQUENCY, GHZ	2.50	
4	ATMOSPHERIC LOSS, DB	0.50	
5	POLARIZATION LOSS, DB	1.00	
6	RAIN ATTENUATION, DB	0.00	
* 7	SCINTILLATION LOSS, DB	0.00	
8	SGL RECEIVED POWER, DBWI	-157.92	
* 9	RECEIVER G/T, DB/K (0dB, 200K, omni)	-23.01	0.00
10	UNBUDGETED RECEIVE LOSS, DB	0.00	
11	BOLTZMANN'S CONSTANT, DBW/HZ-K	-228.60	
12	SGL P/No, DB-HZ	47.67	
13	PAYLOAD RETURN BANDWIDTH, MHZ	10.00	
14	REFERENCE BANDWIDTH, DB-HZ	70.00	
*15	SIGNAL SUPPRESSION, DB	0.00	
16	SGL P/N (TOTAL), DB	-22.33	0.00
17	C/N AT GROUND, DB	-22.33	
18	C/No AT GROUND, DB-HZ	47.67	
*19	TOL DWELL TIME, DB [(2**13 -1)*Tc]	-30.87	
20	MATCHED FILTER OUTPUT C/N, DB	16.80	0.00
21	REQUIRED C/N, DB	15.00	
*22	IMPLEMENTATION LOSS, DB	2.00	
*23	OTHER SYSTEM LOSSES, DB	0.00	
24	TOTAL REQUIRED C/N, DB	17.00	
25	MARGIN AGAINST REQUIREMENT, DB	-0.20	
26	MARGIN TOLERANCE, +,-	-0.20	

Table 1. Power budget for channel characterization experiment.

UP-LINK	
Transmit Power (20 W)	13 dBW
Antenna Gain	0 dB
EIRP	13 dBW
Range	2000 Km
Frequency	1.6 GHz
Free Space Loss	-162.5 dB
Atmospheric Attenuation	-0.5 dB
Total Propagation Loss	-163.0 dB
Receiver's Antenna Gain	3 dBi
Polarization Loss	-1 dB
RF Loss	-1 dB
Received Carrier Power	-149 dB
Receiver's Noise Temp (400 K)	26 dBK
Noise Density (No)	-202.6 dB
Received C/No	53.6 dB
Bandwidth (5 MHz)	67 dB
Received C/N	-13.4 dB

DOWN-LINK	
Transmit Power (0.1 W, Signal only)	-10 dBW
*** Assume 5W full power output ***	
Antenna Gain	3 dBi
EIRP	-7 dBW
Range	2000 Km
Frequency	2.5 GHz
Free Space Loss	-166.4 dB
Atmospheric Attenuation	-0.5 dB
Total Propagation Loss	-166.9 dB
Receiver's Antenna Gain (1m dish)	26 dBi
Polarization Loss	-1 dB
RF Loss	-1 dB
Received Carrier Power	-149.9 dB
Receiver's Noise Temp (100 K)	20 dBK
Noise Density (No)	-208.6 dB
Received C/No (Downlink)	58.7 dB
Total received C/No (uplink + downlink)	52.4 dB
Data rate (9.6K)	40 dB
Receiver's Eb/No	12.4 dB
Required Eb/No (10E-4)	6.5 dB
Coding Gain	5 dB
Implementation loss	2 dB
Margin	6.9 dB

Table 2. Power budget for real-time voice communications.

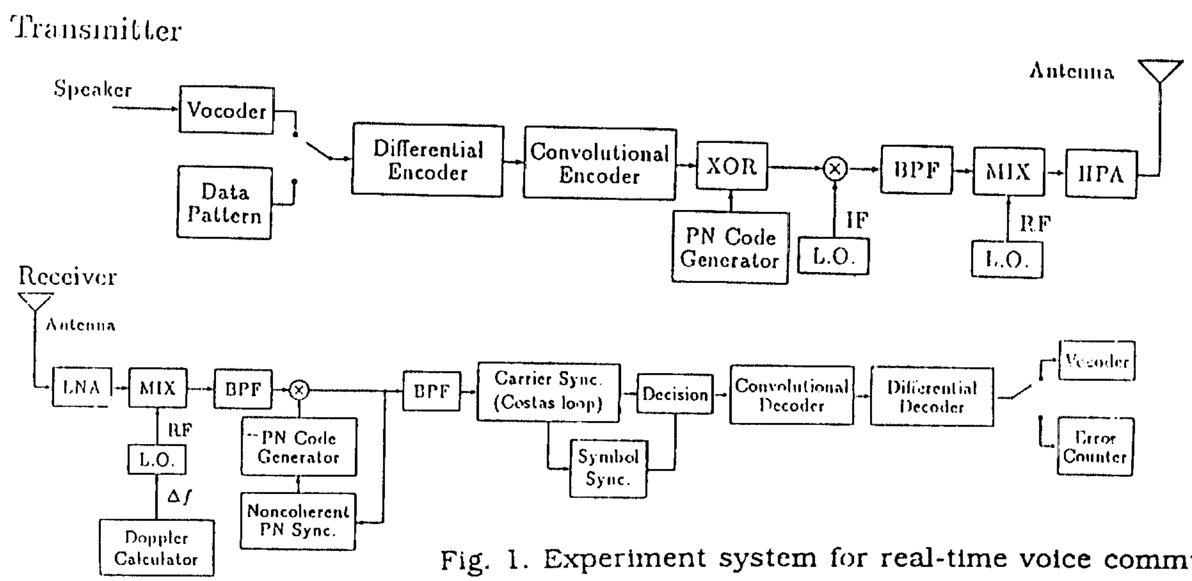

Fig. 1. Experiment system for real-time voice communications.

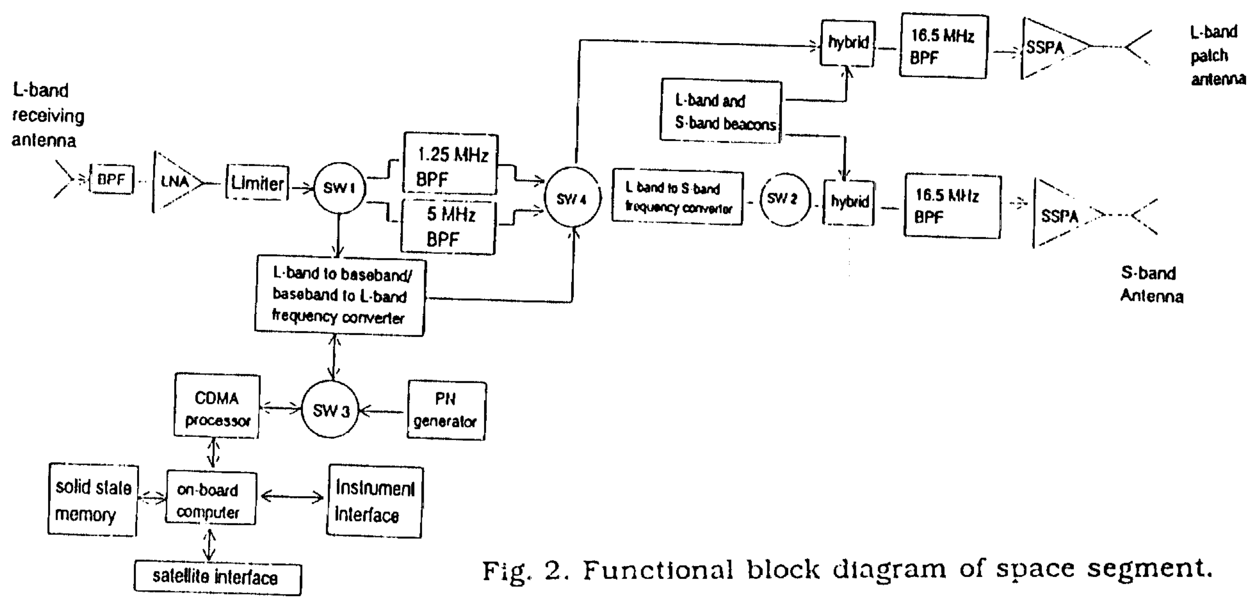

Fig. 2. Functional block diagram of space segment.