

REPORT 1175*

406 MHz GEOSTATIONARY SATELLITE DISTRESS ALERTING EXPERIMENT

(Question 90/8)

(1990)

1. Introduction

The use of satellites for handling of safety and distress communications is of great importance. Since September 1982, the low-altitude, polar-orbiting COSPAS-SARSAT** system has been providing locations of distress situations using the 121.5 and 406 MHz frequencies. These locations are calculated using the Doppler effect on transmitted distress signals resulting from the passing of a moving satellite over the stationary emergency position-indicating radiobeacon (EPIRB). The use of geostationary satellites for relaying 406 MHz satellite EPIRB transmissions is also being evaluated (Report 761).

Indeed, the low-altitude, polar-orbiting and the geostationary satellite systems are complementary in providing safety and distress alerting and locating. For example, a geostationary satellite system can consistently provide near-instantaneous alerting, but in the higher latitude regions above 75°, the coverage is either limited or not at all possible. However, the polar regions are adequately covered by the low-altitude, polar-orbiting system. Data from low-altitude, polar-orbiting satellites are subject to distress alerting delays due to the intermittent passing of satellites. The delays are greatest at the equator and they depend on the number of satellites and on the number and location of receiving earth stations. A geostationary satellite system can provide instant alerts but no location based on Doppler measurements since there is no relative velocity between the satellites and EPIRBs. Other means of establishing location, e.g. user identification or relay of coordinates, may be used with geostationary satellites. There is a case, therefore, for combining the advantages of geostationary and low-altitude, polar-orbiting satellite systems.

A 406 MHz geostationary satellite distress alerting experiment was started in 1984 and is being conducted by the United States of America (USA), France, and Canada. This report summarizes the work conducted and the results obtained by the three countries.

2. Experiment description

An experiment was initiated in the USA by the National Aeronautics and Space Administration (NASA) to evaluate the feasibility of using geostationary satellites for augmentation of the COSPAS-SARSAT system and to improve the efficiency of search and rescue (SAR) operations [Friedman, et al., 1984]. NASA launched a 406 MHz repeater aboard the USA Geostationary Operational Environmental Satellite (GOES)-7 in February 1987 and developed an

* The Director, CCIR, is requested to bring this report to the attention of the International Maritime Organization (IMO), the International Civil Aviation Organization (ICAO), and the COSPAS-SARSAT Secretariat.

** Space system for search of distressed vessels -- search and rescue satellite-aided tracking.

earth station for processing the relayed satellite EPIRB transmissions. The Centre National d'Etudes Spatiale (CNES) in France and the Department of Communications (DOC) in Canada joined the U.S.A. in developing their own earth station processors for reception of the 406 MHz satellite EPIRB transmissions. The satellite EPIRBs used in the experiment conform to the technical characteristics contained in Recommendation 633.

2.1 Objectives

The objectives of the 406 MHz GOES-7 SAR experiment are as follows:

- to demonstrate the feasibility of earth station processors to recover data from 406 MHz satellite EPIRB transmissions that have been relayed through a geostationary satellite;
- to demonstrate that near-instantaneous alerts can be provided for 406 MHz satellite EPIRBs deployed over a range of environmental conditions;
- to determine the technical performance of earth station processors needed to detect the full range of 406 MHz satellite EPIRB signal parameters specified in Recommendation 633;
- to conduct the experiment on an international basis;
- to develop techniques for the integration of distress alert messages received via geostationary satellites into the COSPAS-SARSAT system.

2.2 Experiment phases

In order to accomplish the overall goal, the experiment is being conducted in two main phases: the technical concept verification phase and the system concept verification phase.

2.2.1 Technical concept verification

The technical concept verification was completed in September 1988 and focused on the development of signal processors and on the execution of the engineering tests designed to characterize the performance of the earth station processors as a function of satellite EPIRB transmissions, which undergo various controlled corruptions and/or operate in various environmental conditions. The engineering tests for the technical concept verification were conducted in the following four stages: benchmark tests, spacecraft repeater performance post-launch verification tests, on-orbit tests, and field trials.

During the benchmark test stage, each nation determined its earth station processor's operating characteristics and tested its ground processor's response to corrupted satellite EPIRB signals that were locally-generated and controlled. The benchmark tests included measurement of frequency response, frequency and gain stability, signal processor threshold, effect of missing transmission bursts, time and frequency determination, sensitivity to bit-rate variation, sensitivity to frequency drift, sensitivity of modulation index variation and sensitivity to interference.

The spacecraft repeater performance post-launch verification test stage, completed shortly after the 26 February 1987 GOES-7 launch, included measurement of frequency stability, frequency response of the transponder, satellite amplifier linearity, and intratransponder intermodulation distortion.

The on-orbit test stage was conducted to verify that, as a minimum, the system meets the IMO GMDSS technical requirements. Participants conducted tests to measure signal margin and system

capacity.

The objective of the field trials was to demonstrate that processing of 406 MHz satellite EPIRB transmissions can provide near-instantaneous alert capability under a range of operational conditions. The primary performance criterion was the ability of the earth station processor to detect satellite EPIRB transmissions and process error-free messages.

2.2.2 *System concept verification*

The system concept verification, will continue to explore the response of the ground processors to transmissions from satellite EPIRBs in various environmental conditions. However, the main effort will center on the determination of the best operational method for integrating the alerts received via the geostationary satellite with the information received from the low-altitude, polar-orbiting COSPAS-SARSAT system. Primarily, this will include the tests of the ground network's interconnection between the COSPAS-SARSAT system and the GOES SAR system. Parameters such as the message format, content, and frequency of transmission will be resolved during this phase. In addition, field trial-type tests also may be conducted during this phase.

2.3 *Experiment configuration*

The test spacecraft, GOES-7, used during the geostationary satellite SAR experiment was deployed at 75°W. The USA earth station with special processor is located at NASA Goddard Space Flight Center (GSFC) near Washington, DC and is interconnected with the COSPAS-SARSAT U.S. Mission Control Center (MCC) at Scott Air Force Base near St. Louis, Missouri. The earth station processor in Canada is located at DOC laboratories near Ottawa and is interconnected with the COSPAS-SARSAT Canadian MCC at Trenton Air Base, Ontario. The earth station processor in France was implemented at the Lannion, Brittany, Meteorological Space Center and was interconnected with the CNES Toulouse Space Centre. Satellite EPIRBs were deployed at sea and on the ground. Also, special satellite EPIRB simulators were located at NASA/GSFC and Lannion. These simulators could be varied over the range of satellite EPIRB parameters and were varied in power levels as needed for the conduct of the engineering tests.

2.3.1 *Space segment*

The experiment was designed to be performed with the minimum impact on existing spacecraft design. The GOES-7 spacecraft modifications included a 120 kHz bandwidth receiver channel at 406.050 MHz and a combiner to allow transmission using the same down-link transmitter as the existing data collection platform repeater (DCPR) channel. The transmitter power allocated to SAR has been kept to the minimum possible to avoid degradation of the operational DCPR system.

The GOES-7 SAR repeater was partially incorporated in the intermediate frequency stage of the DCPR which contains a receiver automatic gain control (AGC). The AGC, therefore, responded to the combined power in the two channels. The input G/T was $-18.7 \text{ dB(K}^{-1}\text{)}$. The total downlink e.i.r.p. was +33 dBm, which was shared between the two channels. The gains were adjusted so that with no input from DCPR or satellite EPIRBs, the two channels shared the power equally at an e.i.r.p. of +30 dBm each. A daily operational requirement to relay meteorological data through the DCPR system resulted in a power sharing condition that deteriorated the SARSAT GOES experiment performance. Fortunately, these conditions occurred at planned times and could be avoided during most of the tests. The power sharing between the two channels has been adequate for conducting the experiment but is not recommended for an operational system.

2.3.2 406 MHz satellite EPIRB

The 406 MHz satellite EPIRB signal formats are defined in Recommendation 633. The satellite EPIRBs transmit a digitally modulated carrier burst for about 440 ms (short message format) once about every 50 seconds. The satellite EPIRB signal consists of 160 ms of unmodulated carrier followed by 112 bits of Manchester encoded data that are phase-modulated at 400 bits/s. A Bose-Chaudhuri-Hocquenghen (BCH) (82,61) code that is a shortened form of the BCH (127,106) triple-error correcting code is used in the satellite EPIRB. The BCH code protects 61 data bits that comprise primarily a unique user identity code. The carrier is phase-shift modulated with phase shifts of ± 1.1 radians, which results in some residual carrier in the modulated signal.

2.3.3 Link budget

The link budget, computed for the USA ground station in Table I (similar values are obtained for the Canadian [Keightley, May 1987] and French [Dumont, et al., 1986] earth stations), shows that with 8 active satellite EPIRBs an unfaded carrier-to-noise power density ratio (C/N_0) of 34.9 dBHz is available.

Link degradations of 4-5 dB can be expected under conditions of rough seas, etc. This may result in a received C/N_0 of about 30 dBHz. With such a poor link, a conventional receiver that uses a phase-locked loop to recover the carrier frequency and phase cannot achieve lock. Given that detection of the satellite EPIRB signal and synchronization to it are possible, the theoretical bit error ratio (BER) on the geostationary satellite link is about 3×10^{-2} on a single burst. One approach to achieve acceptable performance is to integrate the satellite EPIRB signal over a sufficient number of burst to a given acceptable BER.

TABLE I - GOES-7 SAR experiment satellite power budgets (for the USA earth station)

Parameter	Value
Uplink	
Frequency (MHz)	406.025
Elevation angle (degrees)	5.0
Satellite EPIRB e.i.r.p. (dBW) (1)	7.0
Polarization loss (dB)	3.0
Free-space loss (dB)	176.9
Satellite antenna G/T ratio [dB(K ⁻¹)]	- 18.7 (2)
Boltzmann's constant [dB(J/K)]	-228.6
Uplink unfaded C/N ₀ (dBHz)	37.0
Downlink	
Frequency (MHz)	1698.65
Elevation angle (degrees)	45.0
e.i.r.p. satellite (dBW) (3)	0.0
Power sharing loss (dB) (4)	15.8
e.i.r.p. per satellite EPIRB (dBW)	- 15.8
Satellite antenna off beam loss (dB)	0.9
Atmospheric attenuation (dB)	0.1
Free-space loss (dB)	188.5
Ground antenna G/T ratio [dB(K ⁻¹)] (5)	15.7
Boltzmann's constant [dB(J/K)]	-228.6
Downlink C/N ₀ (dBHz)	39.0
Uplink C/N ₀ (dBHz)	37.0
Overall C/N ₀ (dBHz)	34.9

Notes:

- (1) Using a linearly polarized antenna with 0 dBi gain.
- (2) On-orbit measured value.
- (3) Per specification.
- (4) Power sharing between noise and 8 simultaneously transmitting signals.
- (5) Using NASA/GSFC GOES Test Laboratory's 7.3 m antenna.

2.3.4 *Earth station*

Each of the participating countries established an earth station. The received satellite EPIRB signals were downconverted and filtered to produce an output, which was then passed through an analog-to-digital converter and processed by a digital signal processor. An all digital signal processing approach was chosen by the three countries because of the amount of signal processing required and because of the flexibility provided.

2.3.4.1 *Conceptual design of the digital signal processors*

The 406 MHz satellite EPIRB has several attributes that permit the development of a technique that allows the demodulation of the received data with acceptable bit error rates. The first characteristic is that the essential portion of the satellite EPIRB message, i.e. the 60-bit field that uniquely identifies the particular satellite EPIRB associated with a specific vessel or aircraft, does not vary from transmission to transmission. This property allows one to develop a means for multiple message integration. By integration of multiple messages, one can increase the effective signal-to-noise power ratio and achieve the desired bit error rate of 1×10^{-5} for the code protected bits. The existence in the 406 MHz signal of a robust error-correction code allows the desired goal of a bit error rate of 1×10^{-5} to be more rapidly achieved.

Based on the above, the three countries have developed processors using the following common base-line requirements capability [Davisson, *et al.*, 1984; Dumont, *et al.*, 1988; Flikkema, *et al.*, 1988; and Keightley, June 1987]:

- operation on individual messages at C/N_0 of less than 30 dBHz;
- identification, collection, and sorting of subsequent messages from a particular satellite EPIRB and performance of integration functions;
- integration of several satellite EPIRB bursts as needed;
- interpretation of the BCH code and performance of appropriate corrections to data;
- operation in the presence of CW interference; and
- operation in near real-time.