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

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* 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 dB(K^{-1}). 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_o (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.

3. Tests description

The tests were designed to evaluate the processor performance (i.e., the receiver sensitivity), system margin, message transfer time (MTT), system capacity, and the affects on the above parameters of geometric and environmental conditions.

Each test, except for the field trials, was organized into units called message blocks; each block consisted of 20 message bursts per satellite EPIRB or, since each burst is repeated every 47.5 to 52.5s, of approximately 17 min transmissions. However, during the field trials, the satellite EPIRBs were normally activated for 30 minute test periods.

3.1 *Receiver sensitivity and system margin*

The receiver sensitivity (processing threshold) was measured during the benchmark and on-orbit tests. It is defined as the minimum earth-station C/N_0 at which a Probability of Detection of an Error-Free (Test) Message (PDEFM) of at least 0.99 is obtained.

To determine the system margin during the on-orbit tests, each country used its own earth station and a satellite EPIRB simulator installed at NASA/GSFC. Emission characteristics of this simulator were in accordance with Recommendation 633. The e.i.r.p. used for system margin tests was equivalent to that of a satellite EPIRB with a lineary polarized antenna transmitting at a 5° elevation angle (see Table I). The system margin is defined as the difference between the minimum e.i.r.p. at which a PDEFM of 0.99 is obtained and the typical e.i.r.p. of 37 dBm.

During the on-orbit test a total of 15 simultaneous simulated satellite EPIRBs were uplinked from the NASA/GSFC simulator. Each simulated satellite EPIRB was assigned an uplink e.i.r.p. that was constant for the duration of the test but differed amongst a number of satellite EPIRBs. Consequently, the margin test also served to demonstrate the capacity of the United States and French processors to handle fifteen satellite EPIRBs simultaneously.

3.2 *Message transfer time*

The message transfer time (MTT) is defined as the minimum time interval between the activation of the satellite EPIRB and the readout of the first error-free message at the earth station. MTT_{50} is defined as the time necessary to receive at the earth station an error-free message from 50% of the detected satellite EPIRBs. MTT_{90} is defined as the time necessary to receive at the earth station an error-free message from 90% of the detected satellite EPIRBs. These parameters were measured during all stages of the technical concept verification phase.

3.3 *System capacity*

The objective of the capacity tests was to determine the capability of the earth station processors to process multiple satellite EPIRBs that were activated simultaneously. Tests were conducted using simulated satellite EPIRBs. The simulators were located at NASA/GSFC and at the CNES earth station installed in Lannion.

3.4 *Field trials*

The field trials were conducted using commercial maritime satellite EPIRBs deployed at specially selected sites. The objective of these tests was the determination of the signal level, and hence the earth station processor, performance degradation caused by such geometric and environmental parameters as the elevation angle, sea state, and wave blockage for maritime satellite EPIRBs.

4. Test results

The technical concept verification tests demonstrated that consistent processor performance was attainable over a wide range of parameter variations. A summary of the more important test results is presented below.

4.1 *Benchmark tests*

4.1.1 *Receiver sensitivity/processor threshold*

The processor performance measured in each country during the benchmark tests is shown in Table II.

TABLE II - *Benchmark test processor performance*

C/No (dBHz)	Canada		France		USA	
	No. of message blocks	PDEFM	No. of message blocks	PDEFM	No. of message blocks	PDEFM
30	10	1.00	240	1.00	-	1.00
29	10	1.00	240	1.00	-	1.00
28	10	1.00	240	1.00	-	0.98
27	200	1.00	240	1.00	-	0.90
26	200	0.705	240	1.00	-	-
25	-	-	240	0.95	-	-
24	-	-	240	0.70	-	-

Based on Table II data, the following receiver sensitivities, or processor thresholds, are noted:

Canadian	processor:	27 dBHz
French	processor:	26 dBHz
USA	processor:	28 dBHz

4.1.2 *Message transfer time*

The message transfer times (MTT_{50}, MTT_{90} or MTT_{95}) obtained in each country during the benchmark tests are shown in Table III. The data indicates that at processor threshold levels $MTT_{50} \leq 8$ minutes and $MTT_{90} \leq 14$ minutes.

TABLE III - *Benchmark test MTT results*

C/No (dBHz)	Canada		France		USA	
	MTT (minutes)		MTT (minutes)		MTT (minutes)	
	50%	95%	50%	90%	50%	90%
32	3	4	1	2	2	3
30	-	-	-	-	3	4
28(1)	5	10	3	4	5	9
27(2)	8	14	-	-	8	15
26(3)	-	-	6	9	-	-
25	-	-	8	13	-	-
24	-	-	11	15	-	-

Notes:
(1) USA processor threshold level.
(2) Canadian processor threshold level.
(3) French processor threshold level.

4.2 *On-orbit tests*

4.2.1 *System margin*

Table IV presents the performance of each processor at e.i.r.p. levels reduced from that of a typical satellite EPIRB (37 dBm). This data was used to determine the on-orbit system margin according to procedures described in §3.1.

TABLE IV - *On-orbit test system performance*

Equivalent e.i.r.p. (dBm)	Canada		France		USA	
	No. of message blocks	PDEFM	No. of message blocks	PDEFM	No. of message blocks	PDEFM
37	288	1.00	360	1.00	-	-
34	576	1.00	-	-	-	-
33	-	-	360	1.00	480	1.00
32	-	-	360	1.00	-	-
31.5	-	-	360	0.99	-	-
31	864	1.00	-	-	-	-
30.5	-	-	-	-	720	0.99
30	864	0.995	360	0.95	-	-
29.5	-	-	-	-	720	0.91
29	864	0.978	360	0.85	720	0.68
28	864	0.891	360	0.50	720	0.21

From Table IV it can be derived that during on-orbit tests, achieved system margins varied from 5.5[***] to 7 dB, depending on the processor and the earth station used. These margins simulating the edge of the satellite coverage, correlate relatively well with the margins predicted on the basis of the measured processor thresholds of 26-28 dBHz and the nominal link C/N_0 of 35 dBHz calculated in Table I.

4.2.2 *Message transfer time*

The message transfer times (MTT_{50} and MTT_{90}) obtained by France and the USA during the on-orbit tests are shown in Table V. The data indicates that at processor threshold levels $MTT_{50} \leq 4.5$ minutes and $MTT_{90} \leq 7.5$ minutes.

TABLE V - *On-orbit test MTT results*

Equivalent e.i.r.p. (dBm)	France			USA		
	MTT (minutes)		PDEFM	MTT (minutes)		PDEFM
	50%	90%		50%	90%	
33	2.5	5.5	1.00	1.5	3.5	1.00
32	4	6.5	1.00	-	-	-
31.5(1)	4.5	7.5	0.99	-	-	-
30.5(2)	-	-	-	3	6.5	0.99
30	6	11	0.95	-	-	-
29.5	-	-	-	4.5	9.5	0.91
29	9	14	0.85	7.5	13.5	0.68
28	12	16	0.50	-	-	-

Notes:

(1) French processor threshold level.

(2) USA processor threshold level.

4.2.3 *Capacity test*

As explained in §3.1, the results of the margin tests demonstrated that the United States and French processors have a capacity to handle at least 15 simultaneously-active satellite EPIRBs. The Canadian processor, although operating in real time, was limited in processing speed, bandwidth and capacity. Thus, there were no further capacity test results reported by Canada.

[***] At the threshold satellite EPIRB e.i.r.p. of 31.5 dBm, the receive C/N_0 is 28.6 dBHz for the French earth station resulting in a threshold degradation of 2.6 dB with respect to the benchmark test result. This degradation was caused by the AGC of the French earth station, which was not adapted to the changes in signal level resulting from the downlink power sharing (see §2.3.1). The above problem will not exist on the next generation of the 406 MHz repeaters installed aboard GOES-NEXT satellites, which will have a dedicated downlink operating at 1544.5 MHz (see §6.2 of Report 761).

4.2.3.1 French processor capacity

The test was conducted to ensure that the processor had the capability:

- to receive and detect 71 satellite EPIRBs on an error-free basis,
- to receive and detect four more satellite EPIRBs, in addition to the 71, on an error-free basis, without the original set affecting the detection waiting time.

Such conditions are very typical of those actually encountered, since each new distress occurs at a time when a number of satellite EPIRBs have already been detected but are still transmitting (other distresses, orbitography beacons, test beacons, etc.).

The test was performed using a CNES simulator installed at Lannion (France).

The simulated satellite EPIRB e.i.r.p. was adjusted to maintain the received C/N_0 at approximately 32 dBHz. The satellite EPIRB frequencies were uniformly spread over a bandwidth of about 20 kHz.

The processor was started up (or reinitialized). A set of 71 simultaneously active satellite EPIRBs was then simulated. Once each of the 71 EPIRBs had transmitted 20 messages, four more satellite EPIRBs were added to the original 71. The test was repeated four times.

The results shown in Table VI demonstrate that the processor had the capability to detect 75 satellite EPIRBs (the first 71 in under ten minutes and the next four in under four minutes).

TABLE VI

Capacity test results

Number of satellite EPIRBs	PDEFM	MTT (min) 50%	90%	No. of detections
original 71	1.00	4	8	284
additional 4	1.00	2	3	16

It must be noted that the use of just two demodulator boards limits the true capacity of the processor. An increase in the number of demodulator boards and improved software will increase its capacity.

A theoretical analysis of the capacity is described in Annex I.

4.2.3.2 *USA processor capacity*

Two types of capacity tests (steady state and incremental) were performed to evaluate the earth station processor performance. In the steady state tests, a constant number of satellite EPIRBs were activated for an entire block of the standard 20 bursts per satellite EPIRB (see §3). In the incremental tests, 40-burst blocks were used.

A total of four tests (two of each type) were performed. Test numbers 1 and 2 were steady state tests with 26 and 30 active simulated satellite EPIRBs. Test numbers 3 and 4 were incremental tests. In test 3, 27 satellite EPIRBs were activated for the first 20 bursts and then, for the next 20 bursts, 3 more satellite EPIRBs were activated in addition to the original 27 already transmitting. Similarly, in test 4, 55 satellite EPIRBs were activated for the first 20 bursts and then, for the next 20 bursts, 4 more satellite EPIRBs were activated. The incremental type of test provides an assessment of the processor's capability to provide an alert for a new distress in a channel already crowded with activated satellite EPIRBs.

The results for the steady-state tests are summarized in Table VII. The average PDEFM for 26 and 27 simultaneously-active satellite EPIRBs was 1.0 and 0.98, respectively, while for 30 satellite EPIRBs it was 0.99. Thus, it can be concluded that the capacity of the earth station processor, while maintaining a PDEFM of 0.99, is about 30 satellite EPIRBs. For 55 active satellite EPIRBs (test 4), the PDEFM was degraded to 0.81. The reason for this degradation has been determined to be an unbalanced processing load between the array processor and the host computer. It is expected that reallocation of the processing load will result in a capacity of over 50 active satellite EPIRBs within a 15 kHz bandwidth for a PDEFM of 0.99 and a MTT_{90} of less than 10 minutes.

TABLE VII - *USA capacity tests: steady-state results*

Test No.	No. of satellite EPIRBs	No. of Blocks	PDEFM	MTT (min)		No. of Messages
				50%	90%	
1	26	8	1.0	0.9	3.4	1156
2	30	8	0.99	0.9	5.3	1154
3	27	10	0.98	0.9	4.1	2995
4	55	3	0.81	1.2	11.7	1076

More information about the earth station processor capacity performance can be obtained from the MTT results. Probably the one most important statistic is the overall MTT_{90}. For 26 active satellite EPIRBs, this overall value was 3.4 minutes; for 30 active satellite EPIRBs, it was 5.3 minutes.

Table VIII gives the results for the incremental satellite EPIRB tests 3 and 4. In both tests, near-instantaneous alerts were generated for all incremental satellite EPIRBs in every block, giving PDEFMs of 1.0. The MTT data is similar to that for the steady-state case, demonstrating the ground processor's capability to detect newly-activated satellite EPIRBs.

TABLE VIII - *USA capacity tests: incremental results*

Test No.	No. of satellite EPIRBs	No. of Blocks	PDEFM	MTT (min)		No. of Messages
				50%	90%	
3	27 → 30	10	1.0	0.9	4.2	182
4	55 → 59	3	1.0	2.5	16.3	43

4.2.4 *Field trial*

The field-trial stage was conducted using maritime satellite EPIRBs deployed at specially selected sites. The objective of these tests was the determination of the earth station processor performance in the presence of geometric and environmental parameters such as the elevation angle, sea state, and wave blockage of the maritime satellite EPIRBs.

In pursuing this objective, two sets of trials have been performed using operational satellite EPIRBs (see Table IX). In one trial, the satellite EPIRBs were deployed off the coast of Brittany, France, on 25-27 May 1988 concurrently with satellite EPIRBs deployed near Chincoteague, Virginia. In the second trial, the satellite EPIRBs were deployed during the period 20 June-2 July 1988 from aboard the La Boheme, a 45 foot sloop, during a trip from Bermuda to Annapolis, Maryland. In general, the sea conditions were calm during these tests.

TABLE IX - *Field trial: satellite EPIRB deployment summary*

Trial	Deployment	Sea State	Elevation Angle
Brittany	On deck/Floating	0.5 m	3.5°-12°
Virginia	Floating	0.5 m	46°
La Boheme	Floating	0.5 m	45°-51°

It is important to note that the test block structure used for the margin and capacity testing was not applicable to the field trials. The field trial deployments were 30 minutes in duration. The ground processor continued to produce messages as long as the satellite EPIRB was being detected. All of the messages were used in generating the statistics.

4.2.4.1 *USA field trial results*

The results of the USA field trials are given in Table X. The third column of the table, P_{DET}, gives the frequency of successful detection for each of the trials. An overall P_{DET} of 0.95 was achieved for the trials. Not all activations were detected within 17 minutes of activation; this is reflected in the PDEFM data. Of the 60 first detections, 2 were after 17 minutes, giving an overall PDEFM for the field trials of 58/63, or 0.92.

TABLE X – *USA field trial results*

	MTT (min)				MTT (min)	
Trial	Trials	Messages	No. of (30 min)	P_{DET} (17 min)	PDEFM 50%	90%
Brittany	32	557	0.94 (30/32)	0.91 (29/32)	1	3
Virginia	15	184	0.93 (14/15)	0.93 (14/15)	2	8
La Boheme	16	317	1.0 (16/16)	0.94 (15/16)	1	4

Table X also shows the MTT data for the field trial messages that were detected under 17 minutes. They show very good near-instantaneous alert performances: 8 minutes or less for MTT_{90}. The Brittany deployments were of particular interest because of their low (down to 3.5°) elevation angle to the GOES-7 satellite. These results are for a total of 1058 data points (messages), giving a fairly high degree of statistical confidence.

4.2.4.2 *French field trial results*

In May 1988, a set of tests was conducted off the shore of Brittany by CNES in collaboration with the French search and rescue services. Two different types of satellite EPIRBs were activated for half-hour periods on deck of a boat or jettisoned into the sea. Satellite EPIRB elevation angles were about 3.5°. The results of these tests are presented in Table XI.

TABLE XI- *French field trial results*

Satellite EPIRB No.	No. of tests	P_{DET} (30 min)	PDEFM (17 min)	MTT (min) 50%	90%
1	29	0.97	0.93	2	6
2	24	0.96	0.92	2	6

A few tests with floating satellite EPIRBs were performed at elevation angles down to 2°. These tests indicate that detection for such low elevation angles is indeed possible. However, detailed data is not available.

5. Conclusions

The GOES-7 technical experiment has shown that a 406 MHz geostationary satellite system can provide rapid distress alerting [Sessions, et al., 1989]. This conclusion is based on the following aspects of the experiment:

— benchmark tests with the USA, French, and Canadian earth stations
  - confirmed that the concept was technically achievable;
  - demonstrated consistent processor performance over a wide range of satellite EPIRB parameter variations;

— on-orbit tests with controlled satellite EPIRB uplinks
  - measured adequate system margins;
  - showed that system capacity of at least 75 satellite EPIRBs operating in 20 kHz band is attainable; and

— engineering field trials demonstrated that operational satellite EPIRBs deployed at sea could be successfully processed.

In summary, this experiment demonstrates that a geostationary satellite system, using 406 MHz satellite EPIRBs that comply with characteristics of Recommendation 633, can successfully meet the capacity requirement discussed in Report 761.

6. Future outlook

As was noted in §2.2, following the technical concept verification, the system concept verification has been undertaken. The main objective of this latter test phase is to assess the usefulness of the alert data received via the geostationary satellite when integrated with the information received from low-altitude, polar-orbiting COSPAS-SARSAT system. Methods of integration of the two sets of data are also being investigated during this phase.

Upon completion of the two test phases, a decision will be made on future use of the geostationary satellite capability. However, it should be also noted that the next generation of GOES satellites (referred to as the GOES-NEXT series), the two Indian INSAT spacecraft (INSAT IIA and IIB), and possibly a Japanese satellite will be equipped with an improved transponder package that should increase the system margin by about 3 dB. These new transponders will be available for use, if desired, starting in the early 1990s and continue into the late 1990s [Dumont, 1988 and Vollmers et al., 1989].

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ANNEX I

MESSAGE INTEGRATION AND RELIABILITY FOR GEOSTATIONARY SYSTEM USING 406 MHz BAND

1. Message integration and alerting time

The use of multiple messages (e.g. majority logic decoding) may reduce the necessary threshold levels. This in turn may reduce satellite antenna gain or increase signal margins but will increase the time necessary for alerting. The alerting time also depends on the number of users. The detailed trade-offs for system capacity and alerting have not yet been undertaken for the geostationary system using the 406 MHz beacons. However, a first estimate may be obtained by considering only message overlap probability with no majority logic decoding.

The probability of mutual interference is given by [Texas Instruments, 1977].

$$P_I = 1 - \left(1 - \frac{2\tau}{T} \cdot \frac{2\Delta f}{F}\right)^{N-1}$$

where:

P_I : the probability of mutual interference

N : the number of satellite EPIRBs in the field of view

τ : the duration of a burst transmission in seconds (440 ms)

Δf: the total signal bandwidth in kHz (1.5 kHz for -10 dB bandwidth)

T: the period between burst transmissions in seconds (50 s)

F: the total search spectrum in which signals may exist in kHz ($F = 8$ kHz)

The quantity F is the band of frequencies over which the satellite EPIRB centre frequencies are distributed. The value for F is estimated from the total search bandwidth of the onboard processor in SARSAT which is 24 kHz [SARSAT, 1979] reduced by the total Doppler excursion (± 8 kHz) which only exists for the low altitude satellite system.

Substituting,

$$P_I = 1 - (0.9934)^{N-1} = 0.4809$$

The probability of no interference on the first burst is P where $P_s = 1 - P$ and on subsequent bursts the probability of at least one burst in j tries without interference is given by:

$$P_{sj} = 1 - P_I^j = 1 - \binom{j}{0} P_s^0 (1 - P_s)^{j-0}$$

The parameter j is related to the maximum delay in alerting, T_a, by $T_a = (j - 1)$T

For $N = 100$ platforms $j = 1$ and $T = 0$ s

$P_{sj} = 0.52$

For $j = 7$, $T_a = 300$ s

$P_{sj} = 0.99$

Using this preliminary analysis it is possible for the geostationary system to provide alerting within 6 min when 100 satellite EPIRBs are within the coverage area. It is necessary to further refine this analysis to carefully consider and include the effects of the actual dispersion of frequencies and the likelihood of detecting and correctly decoding the transmitted messages.

2. Message reliability

The experimental 406 MHz satellite EPIRB message contains a BCH error-correcting code capable of correcting 3 bit errors in the fixed portion of the satellite EPIRB message (82 bits). Using this code, the probability of a message error in the fixed (see Recommendation 633) portion of the message is the probability of the occurrence of four or more errors. Assuming that the errors are independent, the probability of a resulting message error is:

$$p_{mf} = \sum_{i=4}^{82} \binom{82}{i} P_e^i (1 - P_e)^{82-i}$$

where P_e is the probability of a bit error.

For the varying portion of the short message (6 bits) the probability of a message error is not improved by the code and is given by:

$$P_{mv} = 1 - (1 - P_e)^6$$

For the optional long message (32 additional bits) the probability of a message error is given by:

$$P_{ml} = 1 - (1 - P_e)^{32}$$

Table VI gives results for two different bit error probabilities.

TABLE VI

P_e	P_{mf}	P_{mv}	P_{ml} (optional long)
10^{-2}	8.0×10^{-3}	5.9×10^{-2}	0.28
10^{-3}	1.8×10^{-5}	6.0×10^{-3}	3.2×10^{-2}

Thus for a 10^{-3} bit error probability, the message error is reasonably small in all cases ensuring correct reception within a few message repetition intervals.

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