REPORT 761-3*

TECHNICAL AND OPERATING CHARACTERISTICS OF DISTRESS SYSTEMS IN THE MOBILE-SATELLITE SERVICE

(Question 90/8)

(1978-1982-1986-1990)

1. Introduction

The use of mobile-satellite services for the handling of safety and distress communications in the Global Maritime Distress and Safety System (GMDSS) has been developed by the International Maritime Organization (IMO) and will be introduced through the 1988 Amendments to the International Convention for the Safety of Life at Sea (SOLAS), 1974, during the period between 1 February 1992 and 1 August 1999. The specific requirement for carriage of satellite EPIRBs by all ships to which Chapter IV of the 1974 SOLAS Convention applies, will enter into force on 1 August 1993. The GMDSS will use the International Maritime Satellite Organization (INMARSAT) system for communications as well as satellite emergency position-indicating radio beacons (satellite EPIRBs) operating through the COSPAS-SARSAT** system or the INMARSAT system for distress alerting and positioning.

This report considers the major factors that influenced the design of maritime distress systems using satellites and the associated technical and operating characteristics. Section 1 reviews the present terrestrial distress systems, the development of the satellite EPIRB concepts, and the operational requirements for satellite EPIRBs to be used in the GMDSS. Section 2 discusses some of the considerations taken into account in the development of such operational requirements. The technical requirements depend on various techniques used in individual systems; however, some of the considerations taken into account during the decision on technical trade-offs, are reviewed in § 3.

In § 4, a brief delineation of the characteristics of various candidate systems designed to operate through geostationary satellites at 1.6 GHz and tested during the CCIR coordinated trials programme (CTP) is given. Also included in this section is a more detailed description of the 1.6 GHz system accepted for the GMDSS as a result of these trials and subsequent pre-operational demonstrations.

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

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

Section 5 briefly describes the low polar-orbiting system using the 406 MHz band and summarizes the test results obtained during an 18 month demonstration and evaluation phase. The plan for assessing the feasibility and the desirability of operating this system in conjunction with the geostationary satellites and the description of the future geostationary satellite design improvements are contained in § 6. Also included in this section are feasible techniques for position updating of satellite EPIRBs operating through a geostationary satellite and a radiodetermination-satellite service system proposed for operation in the United States.

A summary of the highlights of the Report is given in § 7. Areas for further study needed to standardize systems are given in Annex I.

1.1 Present terrestrial distress system

Statistics published by Lloyds of London show that there was a loss of 1113 vessels of over 100 gross tons for the year 1982. The growth of world-wide shipping and the introduction of larger, faster, more capital-intensive vessels will result in an increasing threat to loss of life and property at sea.

The probability of human survival decreases rapidly with time, following a distress occurrence, in particular, in cold weather conditions or where the survivors are in the sea. It is, therefore, fundamental to any distress system that the existence of the distress occurrence and its location be made known to those capable of rendering assistance in the minimum practical time. The present maritime distress system is based on a complicated interlinking of several elements, and uses telephony, Morse code telegraphy, or EPIRBs on existing allocated terrestrial frequencies. In most cases, the transmission of the message requires manual activation and manual operation. The successful receipt of a distress message depends on the propagation characteristics of the various available frequencies which in turn depend on the geographical location, the time of day, and season. Delays of several hours may result. Past failure to successfully execute a rescue, in some cases, has raised considerable concern internationally about the adequacy and effectiveness of distress and safety communications.

In order to overcome some of these problems, EPIRBs using terrestrial frequencies were developed for homing purposes and for alerting ships in the vicinity, overflying aircraft, and shore stations of the occurrence of a distress. These EPIRBs have two separate designs:

- float-free, which is automatically activated in event of a ship sinking;
- manually activated, when used in survival craft.

The advent of maritime communication satellites (INMARSAT) presents the possibility of overcoming the problems referred to above. In addition, low altitude, polar-orbiting satellites as used in the COSPAS-SARSAT system have demonstrated a significant improvement in the monitoring and locating capability of the EPIRBs operating at 121.5/243 MHz.

Regulation III/6.2, Chapter III of the International Convention for the Safety of Life at Sea, 1974, in force prior to 1 February 1992, refers to radio life-saving appliances, and states that each ship to which the Convention applies shall carry on each side of the ship a manually activated EPIRB operating on 121.5 MHz and 243 MHz. However, to perform the locating function, the 1988 amendments to the 1974 SOLAS Convention have replaced this requirement with survival craft 9 GHz radar transponders conforming to the IMO performance standards; in this case the ship should also carry a float-free satellite EPIRB in order to provide the alerting and positioning functions.

1.2 *Space systems and satellite EPIRB concept development*

Satellite links are largely unaffected by propagation variations. A vessel in distress fitted with a ship earth-station would have a priority channel available for the transmission of the distress message. Such a service capability is currently provided by the INMARSAT system. More than 10 000 vessels are currently equipped with INMARSAT ship earth-stations.

There is a need for automatic distress alerting and positioning in the event of a sudden foundering and also if the crew of a ship in distress take to survival craft.

In order to meet these needs, the concept of a satellite EPIRB dedicated to providing distress alerting via satellite has evolved. Such equipment should be capable of fulfilling an alerting role in one or more of the following applications:

- manual activation from the position from which the ship is normally navigated;
- float-free and automatic activation in the case of a sudden foundering;
- manual activation on board the ship or after being carried from the ship to the survival craft.

The same signalling techniques could be used in the three applications.

1.3 Operational requirements

IMO has defined the following operational requirements for float-free satellite EPIRBs:

a) the satellite EPIRB system is a part of the GMDSS and so configured as to promote safety of life at sea in the highest possible manner;

b) to achieve this aim, the alerting and positioning system will cover all navigable waters. From considerations within IMO, it has been agreed that the long range alerting function of the GMDSS will be based primarily on the use of satellite techniques and will include the use of satellite EPIRBs;

c) the float-free satellite EPIRBs will operate, for ships sailing in all sea areas, on 406 MHz through the COSPAS-SARSAT system, or, for ships sailing in areas within the coverage of geostationary maritime communication satellites, on 1.6 GHz through the INMARSAT's geostationary space segment (subject to the availability of appropriate ground support and processing facilities for each ocean region covered by INMARSAT satellites).

(d) The satellite EPIRB system should take into consideration the requirements of the aeronautical mobile service where a shared system might yield mutual benefits to both services and to search and rescue organizations.

(e) Satellite EPIRB signals are distress messages and will be correctly routed to the appropriate search and rescue authorities.

(f) The satellite EPIRBs should operate for sufficient time to ensure a 0.99 probability of distress message reception and interpretation. It is desirable to achieve this probability as quickly as possible; however, the exact specification of this time will be dependent on system characteristics and implementation.

(g) In regard to the number of simultaneous transmissions of satellite EPIRB alerting signals in any one ocean area, IMO is of the opinion that a satellite EPIRB system should support at least 20 satellite EPIRBs in a 10 min interval. In obtaining this estimate, both IMO convention and non-convention vessels were considered in an entire ocean area. The system should support this with a probability of 0.95. (However, in deriving this capacity figure, no consideration was given to the possible use of the system by the aeronautical and land mobile communities or to the possibility of satellite EPIRB generating false alarms.)

(h) The 1.6 GHz and the 406 MHz satellite EPIRB systems will provide information in accordance with Recommendations 632 or 633, respectively.

2. Operational considerations

The operational requirements identified by IMO for satellite EPIRBs, listed in § 1.3, call for world-wide coverage with minimum possible delay in the receipt of the distress message, together with a capability for the simultaneous reception of multiple transmissions. The preparation of operational requirements for a maritime distress system is the responsibility of the IMO. However, the following considerations are sought to be relevant to these requirements:

- message transfer time and receiver sensitivity;
- system capacity;
- resistance to interference;
- coverage;
- effect of various sea states and environmental conditions on performance;
- contents of distress message and nature of distress;
- methods of positioning;
- maintenance of system integrity;
- the complexity and cost of the distress system.

2.1 *Message transfer time (MTT) and receiver sensitivity*

The message transfer time (MTT) is defined as the time between the initiation of transmission by the satellite EPIRB and the read out of an error-free message at the receiving earth station with a 0.99 probability.

The receiver sensitivity is defined in terms of the minimum average C/N_0 at which the performance of the system remains within the IMO specified message reception probability of 0.99.

With polar orbiting satellite systems operating at 406 MHz, the MTT will include a waiting time between satellite passes. The MTT is thus a function of latitude, orbit, and the number of satellites. However, an additional factor is related to the number and location of receiving earth stations. Operationally, once a satellite is in view of the transmitting satellite EPIRB, the distress message is received and stored on-board the satellite. If a receiving earth station is in view of the satellite, the message will be immediately transmitted to the ground. However, if no receiving station is in view, the stored message will be held until an earth station comes into view. The MTT in the second case will be greater because of the added delay while the receiving earth station comes into view of the satellite.

2.2 *System capacity*

The system capacity is defined as the ability of the system to process a number of near-simultaneous transmissions with a probability of 0.95 without suffering degradation within the maximum allowable MTT or requiring additional satellite EPIRB transmitter power.

2.3 *Resistance to interference*

Resistance to interference is defined as the ability of the system to meet the IMO specified message reception reliabilities in the presence of a variety of interference types (of maximum specified power levels and minimum frequency separations) without suffering degradation within the maximum allowable MTT or requiring additional satellite EPIRB transmitter power.

2.4 *Coverage*

Systems designed to use geostationary satellites will have their coverage limited to latitudes approximately between the 70° parallels but would still serve the majority of world shipping. However, to provide coverage of the polar regions, polar orbiting satellites would be necessary. With polar orbiting satellites, distress alerting delays due to the intermittent passing of satellites will occur. 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. One advantage of polar-orbiting satellites is that real-time position information is obtainable by Doppler measurement of the received satellite EPIRB signal. Up-dating of the distress position using Doppler measurement could expedite the search when satellite EPIRBs are carried on board survival crafts.

There appears to be a case, therefore, for combining the advantages of geostationary and polar-orbiting satellite systems.

2.5 *Effects of various sea states and environmental conditions on performance*

Systems adopted for use in the GMDSS must be capable of operating under extremely adverse sea states and environmental conditions without suffering degradation within the maximum allowable MTT or requiring additional satellite EPIRB transmitter power and should still meet the IMO specified message reception probability.

2.6 *Contents of distress message* **and nature of distress**

The distress message should provide, as far as possible, all relevant information about the incident. However, in the interest of decreasing the probability of error and also message acquisition time, the contents of the distress message should be limited to that which is essential. The possible contents of the 1.6 GHz and the 406 MHz distress message and the nature of distress indications are given in Recommendations 632 or 633, respectively.

2.7 *Methods of positioning*

Upon determination that an emergency or distress exists, the problem becomes one of determining the geographical position of the distress to a sufficient accuracy so that assistance can be effectively rendered.

Geostationary satellites can be used for position location by re-transmission of position data obtained by satellite EPIRBs from on board navigational systems, or by re-transmission of signals received by satellite EPIRBs from existing radionavigation or navigational satellite systems. Low-orbiting satellites can use either of these methods or can determine real-time satellite EPIRB position by Doppler shift measurements of the received satellite EPIRB signals.

2.8 *Maintenance of system integrity*

In the interest of the users, it would be highly desirable to ensure continued availability of adequate space segment facilities which meet the technical requirements that need to be established.

There may also be a need for the establishment of mandatory technical requirements for the satellite EPIRB, appropriate certification procedures, and the maintenance of an up-dated register.

2.9 *The complexity and cost of distress* system

In the interest of widespread acceptance, the complexity and cost of shipboard, satellite, and coast earth station equipment for distress alerting and locating should be minimized. In particular the cost to the user should be as low as possible.

3. Technical considerations

3.1 *Satellite orbits*

Two alternative satellite orbits are being considered: geostationary (at an approximate altitude of 36 000 km) and low altitude, near-polar (at an approximate altitude of 850 km). The satellite EPIRB should provide sufficient energy for maximum operational slant ranges. At 5° elevation angle these respective ranges are approximately 41 000 km and 3000 km.

Another parameter to be considered is the resultant satellite earth coverage antenna beamwidth at the half power points. In the case of the geostationary satellite this beamwidth is around 17.3°, and for the low altitude satellite it is about 123°.

3.2 *Frequency considerations for distress systems*

The band 406-406.1 MHz is exclusively allocated to the mobile-satellite service (Earth-to-space) for satellite EPIRB use and development. The band 1645.5-1646.5 MHz is also allocated exclusively to the mobile-satellite service (Earth-to-space) and is limited in use to distress and safety operations. The bands 121.45-121.55 MHz and 242.95-243.05 MHz are allocated by footnote to the mobile-satellite service for reception on board satellites of EPIRBs transmitting at 121.5 MHz and 243 MHz.

As a practical matter the up-link frequency choice is limited to the 406 MHz and 1.6 GHz bands. Either of these could be used with geostationary or near-polar orbiting satellites. Majority of trials with geostationary satellites have used the 1.6 GHz band because this band is used for normal communications; however, during the 1987-1989 period a number of experiments were also conducted at 406 MHz (see § 6.2). On the other hand, the tests with polar-orbiting satellites have been performed exclusively at 406 MHz because of long-term experience with operational 401 MHz meteorological satellite data collection systems.

The band 1544-1545 MHz is allocated exclusively to the mobile-satellite service (space-to-Earth). It is limited to distress and safety operations including feeder links of satellites needed to relay the emissions of satellite EPIRBs to earth stations and narrow band (space-to-Earth) links from space stations to mobile stations. Feeder links could also operate in fixed-satellite service bands used for normal satellite-to-Earth communications (e.g. 4 GHz band). Either down link could accommodate geostationary-satellite operations. However, feeder links for near-polar orbiting satellites would be limited to 1545 MHz, since geostationary satellites have priority in fixed-satellite bands (No. 2613 of the Radio Regulations) and power flux-density limits in the 4 GHz band make large earth-station antennas necessary.

The other frequencies allocated in the maritime mobile satellite service may be used for distress and safety purposes.

The COSPAS-SARSAT system using low altitude, near-polar orbiting spacecraft has adopted the 406 MHz band for the up link and a part of the 1544-1545 MHz band for the feeder link (space-to-Earth).

The first generation INMARSAT geostationary-satellite system does not have a 406 MHz capability; however, it provides a 1.6 GHz satellite EPIRB capability with feeder links in the 4 GHz band. Future generations of INMARSAT satellites are expected to continue this provision.

3.3 *Interference considerations*

The bands for the space-to-Earth feeder link (e.g. 4 GHz band) are heavily used for fixed-satellite systems. These bands are also allocated to other services such as fixed and mobile services. At this time, a channel is not allocated exclusively for satellite EPIRB use. The two bands 1544 to 1545 MHz and 1645.5 to 1646.5 MHz are allocated on an exclusive basis to the mobile-satellite service and are limited by a footnote to distress and safety operations.

3.3.1 *Interference from radio relay equipment*

A particular site selection for radio relay equipment could cause interference to a satellite EPIRB signal under certain circumstances. This small probability of intereference could be eliminated by avoiding use of those specific channels used by satellite EPIRBs.

The use of suitable frequency co-ordination techniques, such as avoiding pointing at the geostationary orbit, could eliminate even this small probability (see Annex I to Report 917).

3.3.2 *Interference in the 406 MHz frequency band*

The 406 - 406.1 MHz frequency band has been allocated exclusively to satellite EPIRB transmission. This allocation was confirmed by the WARC MOB-83, and a Resolution was approved requesting elimination of all non-authorized transmissions at 406 MHz (Resolution No. 205 (Mob-83)). Subsequently, this Resolution was modified and re-enforced at WARC MOB-87 (Resolution No. 205 (Mob-87)). However, interference is still being experienced continuously by the COSPAS-SARSAT system (Report 919). A method for locating non-authorized transmissions has been successfully developed using COSPAS-SARSAT satellites (Report 979) and interfering transmitters are being eliminated continuously from the frequency band as a result of the IFRB monitoring programme and subsequent actions by the administrations.

4. **Geostationary-satellite systems using the 1.6 GHz band**

4.1 *Configuration*

As an important part of the GMDSS, satellite EPIRBs are required to be carried by all SOLAS ships as of 1 August 1993. It is expected that by this time the second generation of INMARSAT satellites will be operational and that they will be equipped with special amplifiers providing additional gain of approximately 13 dB compared to the normal maritime communication channels, thus resulting in the overall link improvement (down link included) of approximately 5 dB.

Tests in the coordinated trials programme (CTP) were carried out in the band 1644.3-1644.5 MHz using the available INMARSAT space segment. Continued use of this band is anticipated for the lifetime of the first generation space segment. Although it is expected that the second generation INMARSAT space segment will provide a continuing capability in this band, it will be desirable to encourage an eventual transfer of the satellite EPIRB operations to the band 1645.5-1646.5 MHz, which is limited by Radio Regulation No. 728 to distress and safety operation. This latter band will be implemented in the second generation INMARSAT space segment. In order to facilitate introduction of this distress and safety band, and to assure that uninterrupted service will be available to all potential users of satellite EPIRBs in this band, it will be necessary during the transition period to provide for receiver-processors operating in both bands.

4.2 *Coordinated trials programme*

The coordinated trials programme (CTP) of satellite EPIRBs was conducted between January 1982 and April 1983 and is described in Report 1045.

A list of the main characteristics of the systems tested in the CTP is provided in Table I. The capacity numbers shown in this table were derived for CTP conditions and were calculated in accordance with the method given elsewhere [Kaminsky *et al.*, 1983].

As a result of the CTP, the Distress Radio Call System (DRCS), developed by the Federal Republic of Germany, was recommended by the CCIR for the GMDSS. The transmission characteristics of the DRCS are summarized in § 4.3 and are also delineated in Recommendation 632. The CCIR also recommended additional pre-operational demonstrations of this system, and in 1985 the IMO requested that such demonstrations be performed. These demonstrations were successfully completed in 1987 and are described in Report 1184.

TABLE I – *Summary of tested system parameters*

Parameter \ System	DRCS, Germany (Fed. Rep. of)	FSK, Japan	SAMSARS, USA	United Kingdom	PN-PSK, Norway/ESA	SADKO, USSR	PN-PSK, Japan
Frequency up-link (MHz)	1645.5-1646.5	1645.5-1646.5	1645.5-1646.5	1645.5-1646.5	1645.5-1646.5	1645.5-1646.5	1645.5-1646.5
e.i.r.p. (W)	0.1	0.15	0.4	8	0.2	0.15	1
Information bit rate/modulation	32 bit/s, non-coherent FSK	63 bit/s, FSK	0.2-0.7 bit/s, bi-phase PSK	10 bit/s, bi-phase PSK	11.61 bit/s, PSK on a sub-carrier	24 bit/s, FSK	2.5 bit/s, bi-phase, PSK
System capacity in 200 kHz bandwidth	33	133	170	218	57	26	407

4.3 *DRCS system description*

After activation, the satellite EPIRB transmits the distress message containing the ship station identity, position information, and additional information as given in Recommendation 632. The transmission is repeated with a pre-selected duty cycle. Additionally, a transmitter for homing purposes is activated.

A block diagram of the system is shown in Fig. 1a. The parallel/serial shift register (memory element) contains the last up-dated distress message as provided through the ship navigation interface. Before transmission, a forward error-correcting code is applied which is described in Recommendation 632. An example of a transmitted data frame could consist of 20 sync. bits (not included in coding), 100 information bits, and 40 parity bits.

After being relayed by the satellite, the distress signal is down-converted at the earth station to the specified intermediate frequency and transferred to the computer-aided multi-channel receiver for satellite EPIRB message detection. The first stages are a down-converter to audio frequencies, an A/D converter, a filter bank, and an energy meter (Fig. 1b). The absolute values of each digital output are summed to provide a measure of the signal plus noise energy. The digital filter bank uses a polyphase principle and analyzes the spectrum with filters of 30 Hz bandwidth and in steps of 15 Hz which thus overlap each other. The channel identification after scanning all outputs follows a special strategy which includes correlation of the frequency offset between two filters which are equal to the transmitted deviation of the FSK signal; in addition, suppression of potential interferers and additional feedback from the bit sync. detector device are provided.

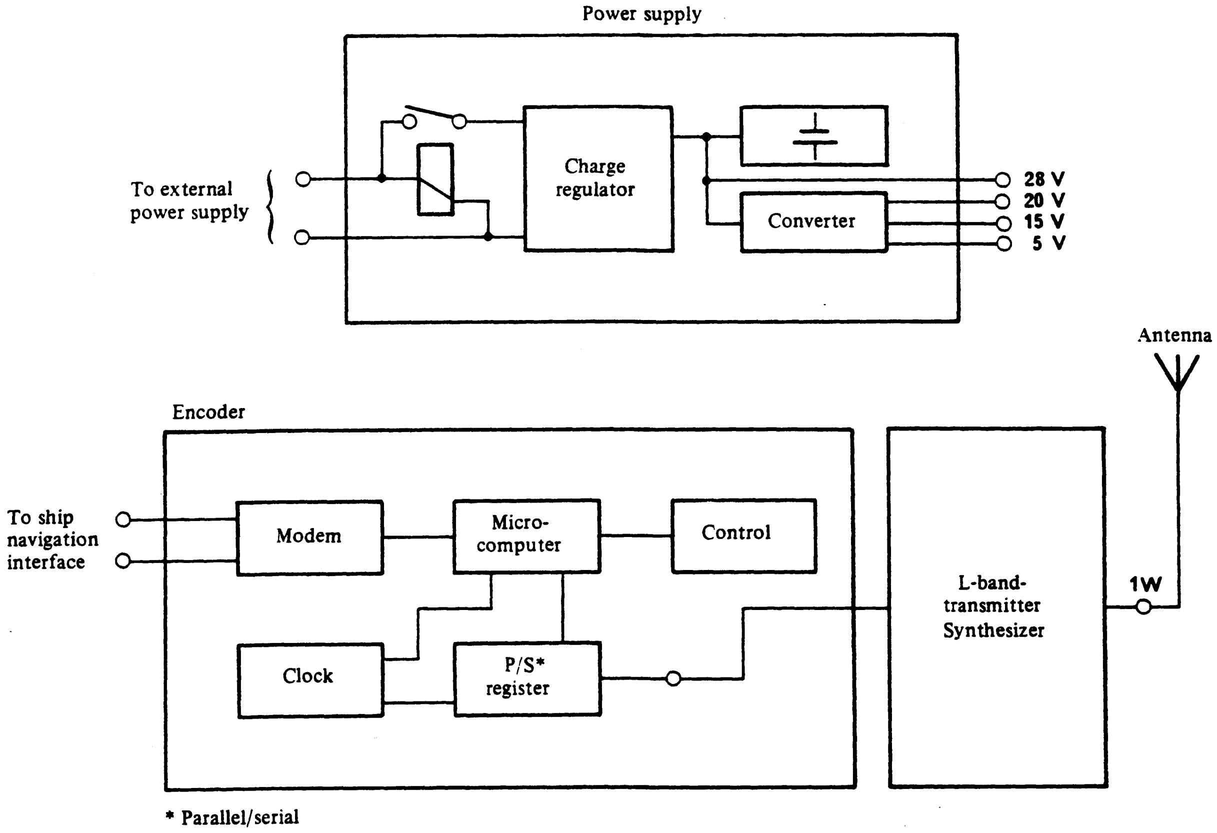

FIGURE 1a – *Block diagram of the 1.6 GHz satellite EPIRB*

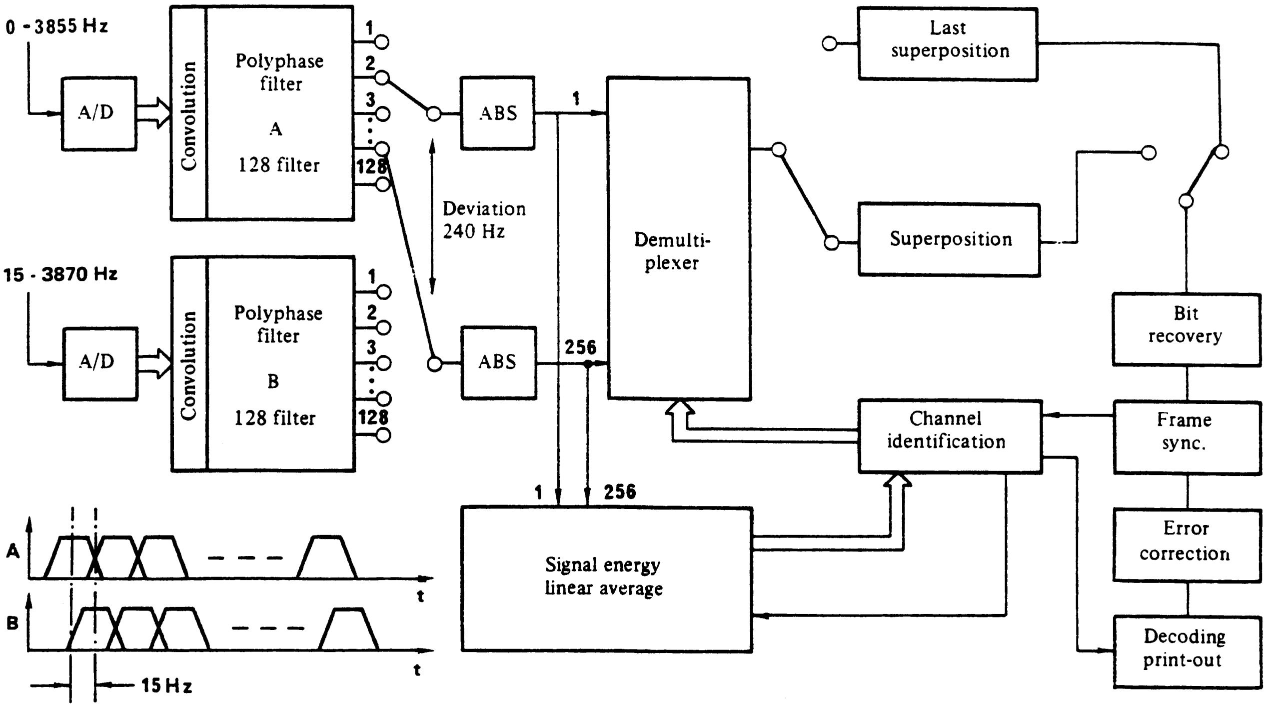

FIGURE 1b – *Functional block diagram of the receiving and detection unit*

A/D: Analogue-Digital converter

ABS: Automatic band switching

After the signal channels are identified, they are assigned to processor channels where the incoming signal plus noise is kept in a memory. In practice every doubling of the number of data frames results in a C/N_0 improvement of approximately 2 to 3 dB.

Every minute, which is equivalent to 12 superimposed frames, the memory is read out to obtain bit sync., frame sync., and for detecting the parity bits of the FEC. If synchronization is achieved and no more than 4 bit errors are detected, the message is decoded and printed out. If more than 4 bit errors are detected, the superposition is continued with a new trial every minute until the message is adequately detected.

The operating characteristics of this system are as follows:

– sensitivity limit for message reception	
– non-fading channel	13 dBHz
– fading channel (1.6° elevation, 2.5 m wave height)	15.1 dBHz
– rejection of interferers outside signal filters (compared signals)	
– CW interferer	> 10 dB
– broadband interferer	> 20 dB
– filter bank search rate (full performance)	60 Hz/s.

The superposition technique integrates all real-time signal fluctuations (Rayleigh distribution) in such a way as to produce a signal with a Gaussian distribution.

The basis of the system is that during all processing procedures, no decision is made prior to signal improvement by the superposition principle. In the data processing unit, an integration time of 10 s is used for superimposing the signal energy equivalent to 10 × 32 = 320 bits upon the noise energy in the time period. The decision for which sample the bit change occurs is made from 160 possible transitions. The decision of a bit being "1" or "0" is made from up to 128 superpositions of the data frame, the minimum being 12.

This signal processing technique is carried out in a non-coherent FSK system. A further important characteristic of this technique is the short acquisition time and the smoothing of the fading effects.

A system with a 1 W transmitter will have a margin of approximately 10 dB which gives additional safety against potential effects due to interference, sun noise degradation on the down link, equipment ageing, unfavourable conditions caused by shadowing by high waves and, to some extent, blockage by the ship. The nominal message transfer time using a 1 W transmitter is 1 min.

The high sensitivity of the receiver processor together with the inherent link margin enable operation at elevation angles down to approximately 0°, thus increasing the coverage area.

4.4 *Other possible applications*

A further application of this satellite EPIRB system is a small portable unit known as a "keyboard sender" which was tested in 1975 with the United States National Aeronautics and Space Administration (NASA) Application Technology Satellite (ATS-6).

The technique of message transfer is identical to the satellite EPIRB system except that a longer data frame is used. Thus, the keyboard sender, which is initiated by hand, is able to transmit not only the distress message of the satellite EPIRB but also an individual message of alphanumeric characters which may be input to a memory by means of a waterproof keyboard. It can be installed on the ship, using the vessel's power supply and connected to a fixed antenna. Under these circumstances it can be used as a reserve transmitter. The same distress keyboard sender may also be easily disconnected in order to be used in a survival craft. The power is then supplied by an internal battery and the signal is transmitted via an antenna which is an integral part of the equipment.

5. **Low altitude, polar-orbiting satellite system using the 406 MHz band**

5.1 *Frequencies and configuration*

The COSPAS SARSAT system was developed in order to receive and process distress alerting, reporting, and position location transmissions from satellite EPIRBs operating in the 406.0-406-1 MHz and the 121.5 MHz frequency bands.

Further background information is contained in [Redisch and Trudell, 1978; Zurabov *et al.*, 1979; COSPAS-SARSAT, 1981; CNES, 1984] and in Report 919.

For the COSPAS system, search and rescue instrument packages are carried on board navigational satellites. For all COSPAS satellites the nominal orbital altitude is 1000 km, inclined 83° with respect to the equator.

For the SARSAT system, search and rescue instrument packages are placed on board meteorological satellites operated by the United States National Oceanic and Atmospheric Administration (NOAA). For all SARSAT satellites, the nominal orbital altitude is 833 km, inclined 98.7° with respect to the equator.

It is planned to maintain two COSPAS and two SARSAT satellites operating in orbit until at least sometime early into the 21st century.

The COSPAS-SARSAT satellite system serves the aeronautical community as well as the maritime community and will, in the future, also serve the land mobile community. This system has been used at 121.5 MHz to significantly augment the existing terrestrial distress alerting, reporting, and position location facilities by providing improved coverage, increased probability of detecting a distress event, and by decreasing the time elapsed between the occurrence of a distress event and its reporting to the SAR authorities.

5.2 *System description*

The satellite instrument package contains receivers operating at 121.5, 243.0 and 406.025 MHz, frequency translators, a signal processor, and a phase modulated transmitter operating in the 1544-1545 MHz band. Signals received by the satellite in the 121.5, 243.0 and 406.025 MHz bands are linearly down-converted and frequency division multiplexed before phase modulating (FDM-PM) the 1544.5 MHz transmitter. The signals received in the 406.025 MHz band undergo additional processing. A two-channel signal processor similar to the ARGOS processor (see Report 538) has been included in the instrument package. The processor demodulates the digital message from the received satellite EPIRB carrier and measures the carrier frequency to an accuracy of ± 0.5 Hz. Two channels of received digital messages and carrier frequency measurements are time tagged, formatted, bi-phase-L encoded, and transmitted in real time at a 2.4 kbit/s rate by direct phase modulation of the 1544.5 MHz carrier. The processed 406.025 MHz information is also stored in the spacecraft memory for later read-out. It is this feature that provides global coverage independent of earth-station location.

The 1544.5 MHz transmissions are received by local user terminals (LUTs). These earth stations use a tracking antenna to achieve an antenna gain-to-noise temperature ratio (G/T) of 3 dB(K^{-1}). The 2.4 kbit/s bit stream is obtained by coherent demodulation of the carrier and is demultiplexed to obtain the satellite EPIRB message, frequency measurements, and time tags. The satellite EPIRB position is computed using the spacecraft ephemeris and time-tagged Doppler shift embedded in the satellite EPIRB carrier frequency measurements. Position location accuracy at 406.025 MHz is of the order of 2 to 5 km.

The linearly translated 406.025 MHz spectrum is also recovered by the coherent demodulation of the carrier and is used primarily for the purpose of characterizing the 406.025 MHz Earth-to-space channel. The characteristics of the 406 MHz satellite EPIRB and the message formats are given in Recommendation 633.

5.3 *Demonstration and evaluation phase*

The COSPAS-SARSAT system demonstration and evaluation phase involving tests at 121.5 and 406 MHz was started in February 1983. Search and rescue agencies and administrations from participating countries were involved in the system evaluation. LUTs and Mission Control Centres have been established in six of the participating countries and operational use of the system began in 1985, after the completion of the demonstration and evaluation phase.

Results of the system demonstration and evaluation are contained in Report 919 and in [CNES, 1984]. Despite the presence of interference in some areas of the world, basic performance requirements of the 406 MHz COSPAS-SARSAT system have been met. These performance requirements are summarized in Table II.

At 406 MHz, the system sensitivity, location accuracy (5 km), and capacity (over 90 simultaneous transmissions) meet or exceed the goal established for the COSPAS-SARSAT system. The trials and participation in actual distress incidents have proven that the COSPAS-SARSAT system provides an effective interaction with SAR services.

TABLE II – *Summary of system operational characteristics*

Operational requirements	Geostationary satellite	Low altitude polar orbiting satellite	Combined geostationary and low altitude, polar-orbiting satellite system
Immediate alerting	Immediate alerting within coverage area	Average of 1 hour for a 4 satellite system	Immediate alerting except average of ½ hour in polar regions with a 4 satellite low altitude polar orbiting system [ORI, 1979]
Identification	In message content	In message content	In message content
Positioning	Re-transmission of NAVAIDs or ship's position	Doppler measurement and possibly re-transmission of NAVAIDs or ship's position	Re-transmission of NAVAIDs or ship's position plus Doppler measurement
Coverage	Limited to approximately between 70° N and 70° S	Global	Global
Nature of distress (optional)	In message content	In message content	In message content

6. Other systems and arrangements under consideration

6.1 *Introduction*

Both low-altitude, polar-orbiting and geostationary satellite systems have been developed and evaluated for use in the GMDSS. These systems are complementary in terms of their ability to provide safety and distress alerting and locating (see § 2.4). Therefore, it appears to be beneficial to combine the advantages of geostationary and low-altitude, polar-orbiting satellite systems (see Table II), particularly when the same frequency can be used for satellite EPIRB transmissions, as preferred by the IMO.

6.2 *Use of geostationary satellites at 406 MHz*

A two-phase experimental programme to evaluate the feasibility of using geostationary satellites in conjunction with the low-altitude, polar-orbiting COSPAS-SARSAT system to relay 406 MHz satellite EPIRB transmission was initiated in mid-1980s by the United States, Canada and France [Friedman et al., 1984; Dumont et al., 1986]. The first phase of this programme, the technical concept verification, was completed in 1988. Its main objective was to characterize the performance of various designs of the earth station processor as a function of satellite EPIRB transmissions, which underwent various controlled corruptions and/or operated in various environmental conditions. The second phase, the system concept verification, completed in mid-1989, centred on the determination of the best method of integrating the alerts received from both the geostationary and the low-altitude, polar-orbiting systems; however, the environmental performance data also continued to be collected during this phase. The tests were conducted with satellite EPIRBs conforming to the technical characteristics contained in Recommendation 633 and they utilized the 406 MHz repeater on board the United States NOAA geostationary operational environmental satellite, GOES-7*. The details of the programme and the results obtained to date are provided in Report 1175.

Following these tests, five subsequent GOES satellites, referred to as the GOES-NEXT series, and two Indian INSAT spacecraft, INSAT IIA and IIB, will be equiped with an improved transponder package to work with the 406 MHz satellite EPIRBs. This new transponder package will be available for use, if desired, starting in the early 1990s and continuing into the mid-1990s. Other nations are also considering flying such transponders on their own geostationary satellites.

In order to demonstrate the performance of a combined system, the United States National Aeronautics and Space Administration (NASA) has developed a 406 MHz ground processor and a 406 MHz repeater for the GOES-7 spacecraft. The Centre National d'Etudes Spatiales (CNES) in France and the Communications Research Centre (CRC) of the Canadian Department of Communications have developed similar ground processors.

The 406 MHz geostationary experiment will utilize a ground processor and the GOES-7 spacecraft, integrated with the *in situ* COSPAS-SARSAT system, to determine the role of instantaneous alerting in improving overall SAR operations.

The improved transponder package provided aboard the GOES-NEXT series of spacecraft is expected to yield an overall 3 to 4 dB improvement in the earth station received C/N_0. This improvement will be derived as a result of three modifications in the spacecraft:

- reduction of the receiver RF filter bandwidth from about 120 kHz to 80 kHz;

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* Prior to its launch in February 1987, GOES-7 was designated as GOES-H.

- 1 to 2 dB improvement in G/T due to tapping the signal from the antenna with an optimized diplexer, thus not sharing the power with the data collection platform (DCP) channel; and
- addition of a dedicated down link at 1 544.5 MHz with increased power output, which will occupy a bandwidth of about 200 kHz.

6.3 *Position up-dating for satellite EPIRBs operating through a geostationary satellite*

6.3.1 *Position up-dating using navigation data*

The position up-dating in the polar-orbiting satellite EPIRB system is accomplished by measuring the Doppler shift in the signal received on board the moving satellite in combination with the position of the satellite at the moment of the reception of the signal from the satellite EPIRB. In a satellite navigation system, the position is obtained by using Doppler shift in the opposite direction, i.e. on board the ship, the Doppler shift is measured in the signal transmitted by the moving satellite in combination with the position of the satellite at the moment of transmission. If the transmission of such a moving satellite were received and the satellite EPIRB re-transmits this signal through the geostationary-satellite system to a coast earth station, then position up-dating could be obtained using the navigation satellite position information and the Doppler shift in the signal.

For position up-dating in geostationary-satellite EPIRB systems, two methods are presently provided: the input of actual position data into satellite EPIRBs at regular time intervals is performed either manually during the change of the watch using a keyboard or by automatic data transfer from terrestrial or satellite navigation systems used on board ship. Alternatively a position-determining device could be built into the satellite EPIRB thereby making either an interface with the ship's navigation system or a manual keyboard unnecessary.

Only satellite navigation systems would offer world-wide random access. With a built-in position determination device, the capability for rapid alerting in combination with an independent and near real-time position up-dating for EPIRBs operating through geostationary satellites, could be achieved. If satellite EPIRBs are developed with this capacity, the duty cycle should be reconsidered to include operation over at least 24 h.

The global positioning system (GPS) currently offers one possibility for providing for position determination inside the satellite EPIRB. This system is described in Report 766. Its frequency L_1 = 1575.42 MHz would be close to the EPIRB transmission frequency, and thus the same antenna could be used. GPS provides an accuracy of about 150 m. The first fix would be obtained in about 15 min if the EPIRB was switched on without knowledge of the ephemeris.

Two other potential navigation systems are under study. NAVSAT is a system proposed by ESA for civil users. With 24 satellites in 12 h orbits, at least 6 satellites will be visible from any point of the Earth. The receiving technique is based on Doppler measurements with accuracies similar to GPS. The estimate for the time-to-first-fix is 3 min.

The Global radio navigation system (GRANAS) is a system proposed by the Federal Republic of Germany. With 20 satellites in 12 h orbits, at least 5 satellites will be visible from any point of the Earth. Each Granas satellite would determine its own position by two-way ranging. Each burst used for user position computation, based on pseudo-range measurements, contains the complete position information of the satellite. Thus, the estimation for the time-to-first-fix is reduced to 20 s.

6.3.2 *Position up-dating by other means*

A different approach which would make up-dated position information available at the RCC could be to utilize a satellite EPIRB capable of operating with the COSPAS/SARSAT low polar orbiting satellite system as well as with the geostationary-satellite system (see also § 2.4).

6.4 *Position location and distress signalling using radiodetermination-satellite service systems*

A radiodetermination-satellite service (RDSS) system is currently proposed for operation beginning in 1988 in the United States and nearby coastal waters. It is expected to have the capability of providing position determination and short digital message service to land-based, maritime and airborne users within its service area. The satellite as currently proposed would transmit a continuous carrier to all of its users in the band 2483.5-2500.0 MHz. Those users wishing to have the system compute position information or to send a brief digital message (e.g. distress condition) would respond to certain time markers in the satellite transmissions with a position request and/or a message. The response by the user is transmitted in the frequency band 1610.0-1626.5 MHz and would be received by two or more geostationary RDSS satellites and relayed to a central control earth station. Based on the propagation delay of the signals relayed through the satellites and known information concerning the elevation at the Earth's surface, a computer at the central earth station computes the precise position of the responding user. The user's position could then be sent to the user and/or message relayed to other users. A more detailed description of the RDSS system is contained in Report 1050 and [O'Neill, 1985].

7. Summary

The opportunity for achieving a means of long range distress alerting by the use of satellite techniques has been identified. The possible considerations to be taken into account when deciding on the operational requirements have been suggested.

Extensive experimental work has already been carried out with favourable results. Demonstration of the 406 MHz low-orbiting COSPAS-SARSAT satellite system and a geostationary satellite system has already provided positive results on the use of satellite EPIRBs for search and rescue operations.

Pre-operational demonstration of 1.6 GHz satellite EPIRBs using the INMARSAT satellites has been completed; demonstration of 406 MHz satellite EPIRB transmissions through the United States GOES geostationary environmental satellites began in 1987 and was completed in 1989.

The requirements for carriage by ships of satellite EPIRBs are included in Regulation IV/7.1.6 of the 1988 amendments to the 1974 SOLAS Convention and the IMO performance standards are given for the 406 MHz satellite EPIRB in IMO Assembly resolution A.611(15) and for the 1.6 GHz satellite EPIRB in IMO resolution A.661(16).

The frequency allocations in the 1.5/1.6 GHz bands provide for both communications and distress and safety operations, whereas the allocation at 406 MHz provides an exclusive band for satellite EPIRBs in the Earth-to-space direction. These frequency allocations appear to be adequate.

The 1988 Amendments to the 1974 SOLAS Convention include the use of geostationary and low altitude, near polar-orbiting satellites using different frequencies. The technical, operational, and economic impacts of satellite EPIRBs operating at one frequency via more than one satellite system is being assessed for both the satellites and the earth stations.

It is highly desirable operationally that each system conform to a single international standard.

The resolution of areas requiring further study, as given in Table III of Annex I, is regarded as a necessary step for achieving standardization.

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ANNEX I

This Annex addresses a number of subjects, some of which concern the technical and operational matters still to be resolved or published before either one or the other satellite EPIRB system can be available to users. Others concern administrative and regulatory matters affecting the way such devices may be used.

An X in Table III indicates that it is expected that the related organization will have an active interest in the topic. It should be noted that, although not shown in every table entry, the prerogatives of administrations to assume a role in any of these topics is recognized.

An attempt has also been made to indicate by the symbol ⊗ those organizations which are thought to have a particular responsibility and involvement for study and related development activities.

TABLE III

	ITU CCIR/ CCITT	IMO	INMAR-SAT	Adminis-trations	COSPAS-SARSAT	Manu-facturers
1. The data entry device			X	⊗	X	⊗
2. The data interface with ship's navigational equipment		X	X	⊗		⊗
3. The types of satellite EPIRB packaging and interface arrangements necessary for different applications and ship types and the standard of any associated cabling required		⊗		X		X
4. The specification, design and development of low-cost production satellite EPIRBs and their installation			X	⊗	X	⊗
5. Satellite EPIRB environmental and mechanical requirements, including anything which could affect the probability of equipment survival in hazardous situations (e.g. heavy seas, burning oil, icing)			X	X		X
6. The measures to minimize unwanted and unauthorized satellite EPIRB activations (e.g. means to detect and indicate satellite EPIRB activation)				⊗		X
7. The regulations governing the testing of the complete system including any need for self-checks and periodic inspections		X		X		
8. The duty cycle.	⊗					
9. The type approval requirements and procedures			X	X		
10. The commissioning procedures for the satellite EPIRBs			X	X		
11. Possible radiation hazards and path blockage, especially if the satellite EPIRB is used in a survival craft	X			X		
12. The location and number of satellite EPIRBs carried on ships				⊗		
13. The measures to minimize the repeated print-out of an alert message at RCC		X	X	⊗	X	
14. The communication link requirements needed to implement the IMO distress message routing arrangements and operational procedures	X	⊗	X	X	X	

TABLE III *(continued)*

	ITU CCIR/ CCITT	IMO	INMAR-SAT	Adminis-trations	COSPAS-SARSAT	Manu-facturers
15. The implications of the implementation of a combined polar-orbiting and geostationary satellite system	⊗	X	X		⊗	
16. The effect on satellite EPIRB design and performance resulting from the incorporation of a homing facility			X	X		X
17. The incorporation of 1.6 GHz satellite EPIRB receiving, processing and handling facilities at coast earth stations and related costs		X	X	X		
18. The effects on system reliability resulting from the application of the satellite EPIRB system to users other than IMO convention ships	X	X	X	X	X	
19. The number of coast earth stations to be fitted with receiver processor in each Ocean Region		⊗	X	X		
20. Means of obtaining position up-dates in a geostationary-satellite EPIRB system	⊗		X		X	
21. Means to minimize effects of potential interference	⊗		X	X	X	