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SESSION III

THE COSPAS-SARSAT SYSTEM

by

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ABSTRACT

The COSPAS-SARSAT project is an international effort to demonstrate the use of satellites to detect and locate emergency beacon signals from aircraft and ships in distress. The project involves two interoperable satellite systems: COSPAS launched by the USSR, and SARSAT involving Canada, France and the United States. After extensive technical testing on two COSPAS and one SARSAT (NOAA-8) spacecraft, a system Demonstration and Evaluation Phase began in 1983.

The purpose of this paper is to provide a technical overview of how the COSPAS-SARSAT system functions. The technical objectives and significant system design considerations and constraints are discussed. System operating modes for existing 121.5/243 MHz emergency beacons and experimental 406 MHz beacons are outlined.

SYSTEM CONCEPT

The basic concept of the COSPAS-SARSAT satellite-aided search and rescue mission is illustrated in Figure 1. The signals radiated by either an ELT or an EPIRB are detected by a polar-orbiting spacecraft equipped with suitable receivers. These signals are then relayed to a LUT where the signals are processed to determine the location of the ELT or EPIRB. The fact that an alert has been detected, along with the location of the ELT or EPIRB, is then relayed to an appropriate RCC for initiation of the search and rescue activities.

Doppler-positioning using the relative motion between the spacecraft and the ELT/EPIRB has been chosen as the only practical means of locating these very simple devices. All that is required of the ELT/EPIRB is that it emit a carrier frequency with a reasonable stability during the duration of visibility. Although the 406 test units are more complex through the addition of identification and situation codes, retention of the Doppler-positioning concept allows for minimum complexity in the ELT/EPIRBs. To optimize Doppler-positioning performance, a low-altitude polar orbit is used. The low altitude results in low ELT/EIPRB power requirements, good Doppler-shift characteristics and short time delays between successive passes. The polar orbit results in coverage of the whole earth.

The system is composed of four basic subsystems as shown in the system block diagram (Figure 2):

i) The first subsystem is the ELT and EPIRB. These small emergency transmitters are designed to transmit distress signals in the 121.5/243 MHz and 406 MHz bands.

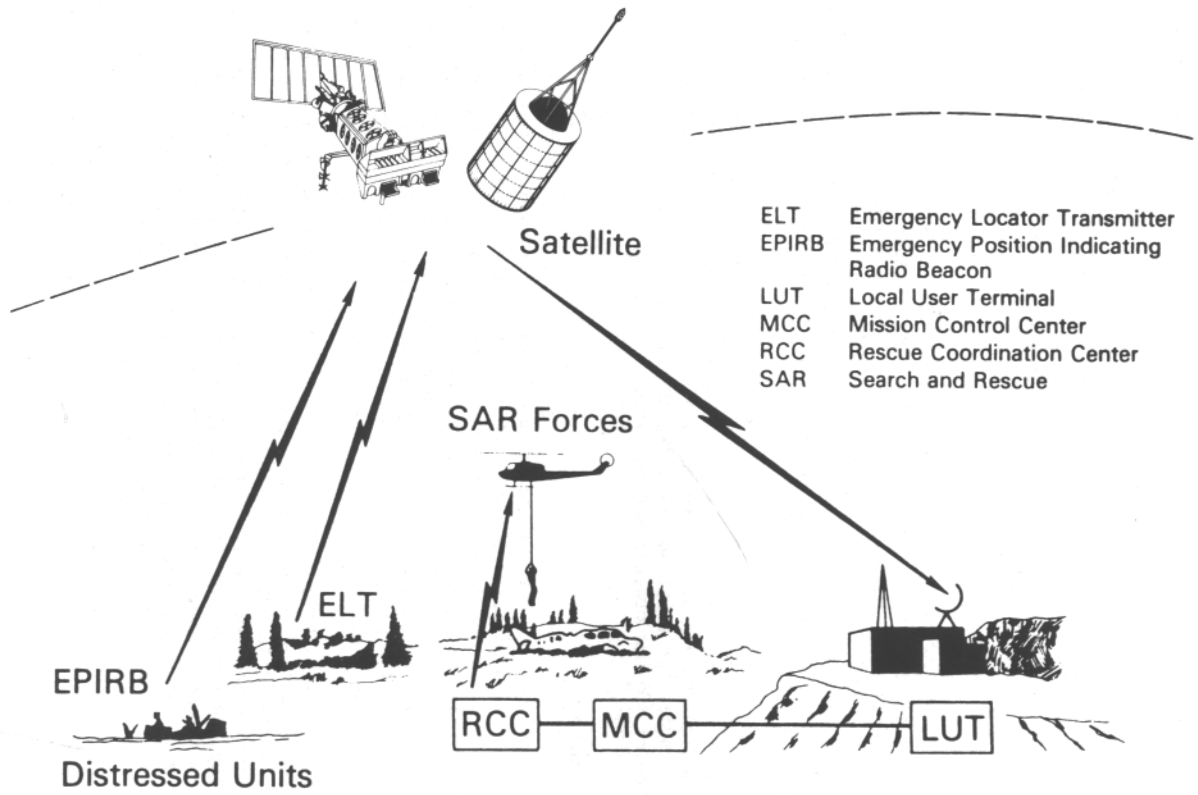

FIGURE 1 BASIC CONCEPT

ii) The second subsystem is the spacecraft (SARSAT and/or COSPAS) which receives these distress messages and retransmits them at 1544.5 MHz to the ground stations for processing. The 406 MHz data are also processed and stored on board the spacecraft for direct transmission to a LUT, or for later transmission to ground stations on command.

iii) The third subsystem is the Local User Terminal (LUT), which is the ground station that receives the relayed distress signals. These signals are then processed within the LUT to provide position location of the distress. This data is then transmitted to the Mission Control Center (MCC).

iv) The fourth subsystem is System Control and Coordination which is accomplished by the MCC in each of the participating countries, and by the communications arrangements between these various MCC's as shown in Figure 2. Exchange of distress incident data or any other data may be arranged between participating MCCs as required. The final destination MCC is then responsible for providing the data to the appropriate national Rescue Coordination Centre (RCC) for SAR action.

To ensure interoperability between the various subsystems, a set of interoperability parameters at the subsystem interfaces were agreed and documented. These are found in Reference 2. Certain key parameters, particularly on the space hardware, were verified by pre-launch interoperability testing.

Within this overall system configuration, it is important to note that two distinct systems have been implemented which are substantially different in their implementation.

i) The 121.5/243 MHz System

The first of these systems involves the use of the existing family of about 300,000 ELTs and EPIRBs which radiate at one or both of the 121.5/243 MHz distress frequencies. It should be recognized that all of the present ELTs and EPIRBs were designed and implemented with no thought of their potential detection by a satellite system. Therefore, their signal characteristics (output power, frequency stability, modulation format, etc.) are far from ideal for satellite detection, which rules out the use of a simple on-board spacecraft signal processor.

Thus, the spacecraft is limited to serving as a repeater for the entire received spectrum at 121.5 and 243 MHz, relaying the signals to the ground where sophisticated processors can extract the signals and determine the Doppler shift. Operationally, this requires mutual visibility of the ELT or EPIRB, the spacecraft, and the LUT.

In spite of the difficulties of the 121.5/243 MHz system, the COSPAS-SARSAT system has substantially improved the capability for ELT and EPIRB detection and location by providing regular systematic coverage and by providing location accuracies of 10-20 km. The capacity of the system is at least 10 ELT/EPIRBs simultaneously in view of the spacecraft. It is the success of this system which has allowed COSPAS-SARSAT to be involved in "real world" distress incidents.

ii) The 406 MHz System

The system at 406 MHz is based upon proven technology which has served the meteorological data collection community for years. The random access measurement system on the Nimbus spacecraft and the ARGOS

COSPAS-SARSAT INTERFACES

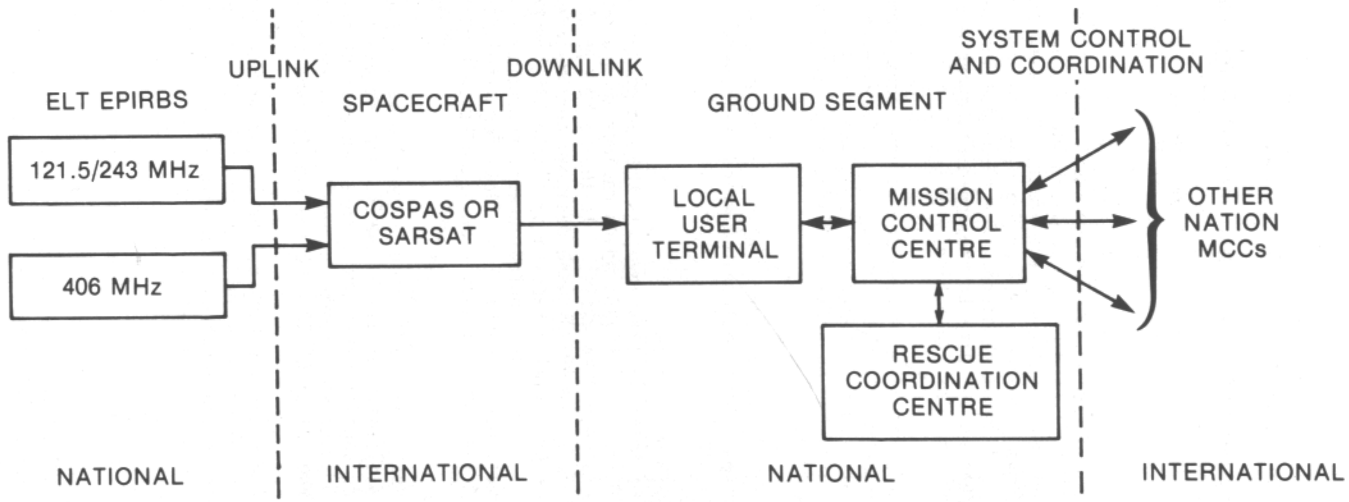

FIGURE 2 SYSTEM BLOCK DIAGRAM

data collection system flying on the NOAA spacecraft are examples of systems of this type. The use of these techniques for search and rescue applications has been demonstrated by a sailboat search and rescue experiment, by the tracking of the manned balloon "Double Eagle" during both the unsuccessful and successful transatlantic crossings, and by the tracking of a number of sailing vessels during several off-shore sailboat races.

The key element in the 406 MHz system is the ELT or EPIRB which is specifically designed to take advantage of the satellite detection system. The higher power and improved frequency stability of the 406 MHz units along with operation at a frequency which was internationally approved during the World Administrative Radio Conference (WARC 79) for the exclusive use of ELTs and EPIRBs will greatly enhance overall system performance compared to the 121.5/243 MHz system. The probability of location of normally transmitted signals exceeds 95% and the location accuracy is better than 5 km.

There are two other significant advantages provided by the signal design of the 406 MHz ELT/EPIRBs. First, a data message can be transmitted with information to distinguish whether the signal is from an aircraft or vessel, its country of origin, the nature of the distress or the elapsed time since the accident, the identification of the vessel or aircraft and, if known, the location of the emergency. This information in itself is of great value to search and rescue forces in responding to the needs of the victims. Additionally, the coherent carrier portion of the transmission is processed by an on-board signal processor which can accurately determine its frequency. This frequency, along with the time of measurement and the decoded message, is then relayed to the LUT in real-time as well as stored in memory on the spacecraft and dumped to the next available ground station. This not only greatly simplifies the processing in the LUT but also eliminates the requirement for mutual visibility of the spacecraft and the LUT while the distress transmission is taking place. Thus, full global coverage including the Arctic regions and ocean areas can be achieved with a relatively small number of LUTs.

The COSPAS-SARSAT subsystems shown in Figure 2 are used to implement two data systems and two coverage modes for the detection and location of ELT/EPIRBs operating in three frequency bands. The two data systems are:

a) Repeater Data System

In the SARSAT system, a repeater onboard the spacecraft relays the 121.5, 243 and 406 MHz signals directly to a Local User Terminal (LUT). At the LUT special processing is used to extract the weak 121.5/243 MHz signals from the noise, recover the Doppler information, and determine the ELT/EPIRB position. The 406 MHz repeater was provided for experimental purposes. In the COSPAS system, a repeater on board the spacecraft relays the 121.5 MHz band.

b) Processed Data System

A 406 MHz data processor is included on both the COSPAS and SARSAT spacecraft. 406 MHz ELT/EPIRB signals are received and detected. The Doppler shift is measured and the ELT/EPIRB identification and status data are recovered. This information is time-tagged, formatted as digital data, and transferred to the repeater downlink for real-time transmission to any LUT in view. Simultaneously, the data is stored on the spacecraft for later transmission to the National Oceanographic and Atmospheric Administration (NOAA) ground stations in the case of a SARSAT spacecraft and to any LUT in the case of a COSPAS spacecraft.

The two coverage modes are (i) regional coverage and (ii) global coverage.

i) Regional Coverage Mode

This mode provides coverage to those areas where the spacecraft is mutually visible to an ELT/EPIRB and a LUT, an area approximately 4000 kilometers in diameter centered on the LUT location. The regional coverage data processing is performed at the LUT.

ii) Global Coverage Mode

This mode provides full-earth coverage by storing data in the spacecraft until it is dumped at the next available ground station. This enables large maritime areas which are out of range of LUTs to be covered. This mode only operates with the 406 MHZ ELT/EPIRB test units.

The interactions of the data systems, coverage modes and frequency bands are illustrated in Table 1.

TABLE 1

COSPAS-SARSAT OPERATIONAL MODES

	Repeater Data System	Processed Data System
Regional Coverage Mode	121.5 MHz 243 MHz* 406 MHz*	406 MHz
Global Coverage Mode		406 MHz

*SARSAT only

ELT/EPIRB DESCRIPTION

1. Existing 121.5/243 MHz Beacons

Table 2 presents a list of the salient characteristics for existing beacons at 121.5/243 MHz. These beacons are in operational use in North American, Europe and other parts of the world, and are required to meet national specifications based upon agreed ICAO standards. The antenna polarization is linear and since most of these units are located in small aircraft and activated by crash sensors, the relation of the polarization to local vertical and the resultant antenna gain are random variables. Test beacons located on the ground for performance verification of the spacecraft systems use vertical linear polarization.

TABLE 2

TYPICAL EXISTING 121.5/243.0 MHz ELT/EPIRB CHARACTERISTICS

Parameter	Value
RF Signal	
• Transmitter Power	50 - 100 mw PERP*
• Transmission Life	48 hours
• Frequency	121.5/243.0 MHz
• Frequency Tolerance	50 PPM
• Polarization	Linear
Modulation	
• Sweep Rate	2-4 Hz
• Range	1600 - 300 Hz
• Modulation Type	AM
• Modulation Factor	90-100%
• Duty Factor	40%

Note: There is no carrier stability specification on ELTs currently in use.

*PERP Peak Effective Radiated Power

2. Experimental 406 MHz Beacons

To overcome the design limitations of existing ELT/EPIRBs and to broaden the capability of the system, a new generation of experimental ELT/EPIRB was developed as part of the COSPAS/SARSAT project. These devices, designed specifically for satellite detection and Doppler position fixing, will result in a system having a number of attributes:

- improved location accuracy and higher confidence level,
- increased system capacity,
- world-wide coverage,
- unique identification of every ELT/EPIRB,
- distress information included in signal and,
- compatability with geostationary satellites.

The characteristics of the new generation of emergency transmitters are given in the Table 3. The new beacons, operating at 406.025 MHz, transmit a pulse of 5 watts of RF power of approximately one-half second duration every 50 seconds. The improved frequency stability and the high peak power provides improved location accuracy, with better than 5 km normally achieved. The low duty cycle provides good multiple-access capability with a system capacity of up to 90 ELTs simultaneously in view of the satellite.

A very significant expansion of the new emergency transmitter capability is the addition of a digitally coded message. Two message formats are provided: (i) a standard message of 88 bits and (ii) an optional long format of 120 bits. The message provides information about the distress vehicle and the distress situation. The optional long message format adds an additional 32 bits, providing capability for latitude and longitude information to be inserted. Further details on the message code can be found in Reference 2.

TABLE 3

COSPAS-SARSAT

406 MHz ELT/EPIRB BEACON CHARACTERISTICS

Parameter	Value
RF Signal	
• Frequency	406.025 ± .001 MHz
• Stability	1 part in 10^9 in 100 msec. 3-5 Hz in 15 min. 2 KHz in 5 years
• phase Jitter	10^0 rms measured in 50 HZ Bandwidth
• Power Output	5 W + 1 dB; -2 dB into 50 Ohms
• Spurious	50 dB below 5 W in 5 MHz Carrier harmonics 30 dB below 5 W
• Data Encoding	Bi-Phase L
• Modulation	Phase modulation 1.1 ± 0.1 radians peak referenced to an unmodulated carrier
• Modulation Rise Time	The rise and fall times of the modulation waveforms must be less than 0.25 msec.
Digital Message	
• Repetition Rate	50 sec ± 5%
• Transmission Time	440 ms ± 1% (short message); 520 ms ± 1% (long message)
• CW Preamble	160 ms ± 1%
• Digital Message	280 ms ± 1% (short message) 360 ms ± 1% (long message)
• Bit Rate	400 Bits/sec ± 5 Bits/sec
• Bit Sync	All "Ones" (Fifteen "ones")
• Frame Sync	000101111

Note: Continuous emission in a failure mode shall not exceed 45 seconds.

C. SPACE SEGMENT

This section provides a very brief descriptive summary of the search and rescue instrumentation on board the SARSAT and COSPAS spacecraft. Further details can be found in Reference 1 and 2.

1. SARSAT PROJECT

A block diagram of the SARSAT spaceborne equipment is shown in Figure 3. It operates in the following modes:

121.5/243.0/406.05 MHz real-time repeater;
406.025 MHz real-time processed data;
406.025 MHz global data storage.

The equipment consists of the following components:

i) the 121.5 MHz 243.0 and 406.05 MHz receivers;
ii) the 406.025 MHz receiver/processor;
iii) Manipulated Information Rate Processor (MIRP);
iv) the 1544.5 MHz transmitter.

2. COSPAS PROJECT

Figure 4 is a block diagram of the COSPAS spaceborne equipment. It operates in the following modes:

121.5 MHz real-time transmission;
406.025 MHz real-time processed data;
406.025 MHz stored data transmission with simultaneous real-time processed data.

The equipment consists of four basic components:

1) the 121.5 MHz receiver
2) the 406.025 MHz receiver/processor
3) the frame formatter and memory unit
4) the 1544.5 MHz transmitter.

D. GROUND SEGMENT

1. Local User Terminals (LUT)

The configuration and specific capabilities of each of the LUTs in the COSPAS-SARSAT participating nations varies somewhat to meet national requirements. The COSPAS and SARSAT spacecraft downlink signal formats were agreed to ensure interoperability between the various spacecraft and LUTs. Further details on these signal formats are available in Reference 2. The locations of LUTs currently in operation are as follows:

Canada : Ottawa

France : Toulouse

Norway : Tromso

U.K. : Lasham

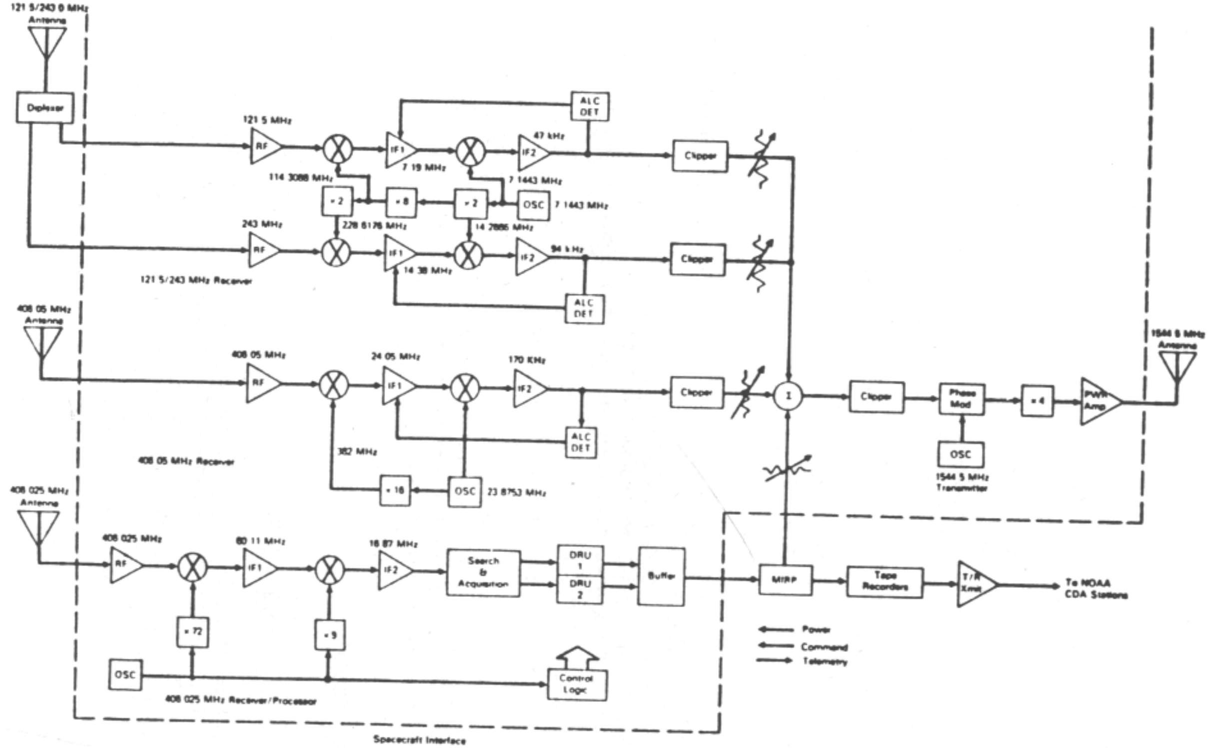

FIGURE 3 SARSAT SPACEBORNE EQUIPMENT BLOCK DIAGRAM

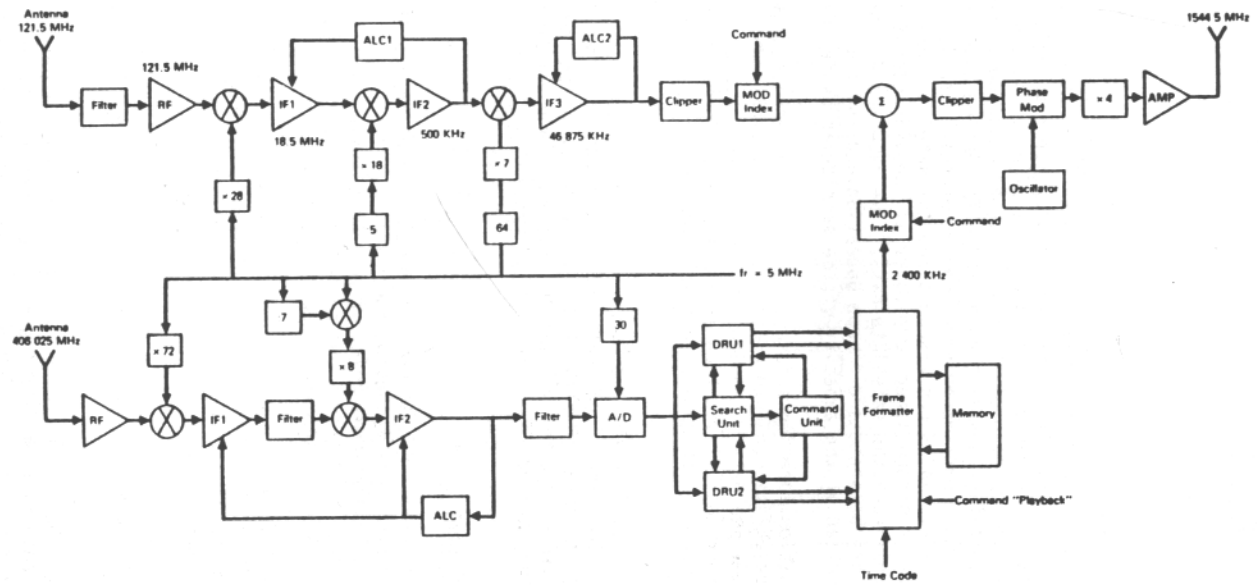

FIGURE 4 COSPAS SPACEBORNE EQUIPMENT BLOCK DIAGRAM

U.S.A. : Kodiak
San Francisco
St. Louis

U.S.S.R. : Moscow
Arkhangelsk
Nakhodka

Figure 5 is a functional diagram of a typical SARSAT LUT. The antenna and receiving system down-convert the signal to an IF frequency, and a linear demodulator produces the composite baseband spectrum which is filtered and separated into the various bands of interest. As the signal is received, the processing of each of the several bands is accomplished depending upon the specific capabilities of the LUT. Analog tape recording of the signals provides a back-up mode in case of processor failure. The 121.5/243 MHz data is partially processed during the satellite pass and then post-pass processing is accomplished to provide all position locations within thirty minutes after the satellite pass. The 2400 bps 406 MHz pre-processed data can be processed in one operation and the time for processing is a function of the capacity of the particular system design.

To improve position location accuracy, an orbit correction update is produced for each satellite received by the LUT. Two methods are used to update the orbit. In one method the downlink carrier is tracked to provide a Doppler signal using the LUT location as a reference. In the other method, local calibration platforms operating a 406 MHz with accurately known locations are used.

Figure 6 is a block diagram of a COSPAS LUT. The antenna and receiving system receive the spacecraft signal and convert it to about 3 MHz. This low frequency signal is then A/D converted and all demodulation and processing is implemented digitally. The 406 MHz pre-processed data is processed in much the same way as in the SARSAT system.

2. Mission Control Centers (MCC)

An MCC has been established in each of the participating COSPAS-SARSAT nations. The MCCs perform the following functions:

- provide an operational point of contact between countries for the exchange of distress and system operational data (orbit updates, calibration data, spacecraft status);
- co-ordination of LUT operations in each country, including reception of the distress location data from the LUTs and distribution of this data to the appropriate Rescue Co-ordination Center (RCC);
- implementation of all other necessary co-ordination between the COSPAS-SARSAT system and the SAR user in each of the respective countries.

In North America the U.S. Mission Control Center (USMCC) provides the focal point for co-ordination of SARSAT satellite operations, calculates 406 MHz locations from stored data obtained through NOAA ground stations, distributes ephemeris data, processes the time calibration data, and forwards the appropriate data to each participant. The USMCC acts as the single point of contact for system operational co-ordination between the SARSAT experiment operations and the COSPAS Mission Center.

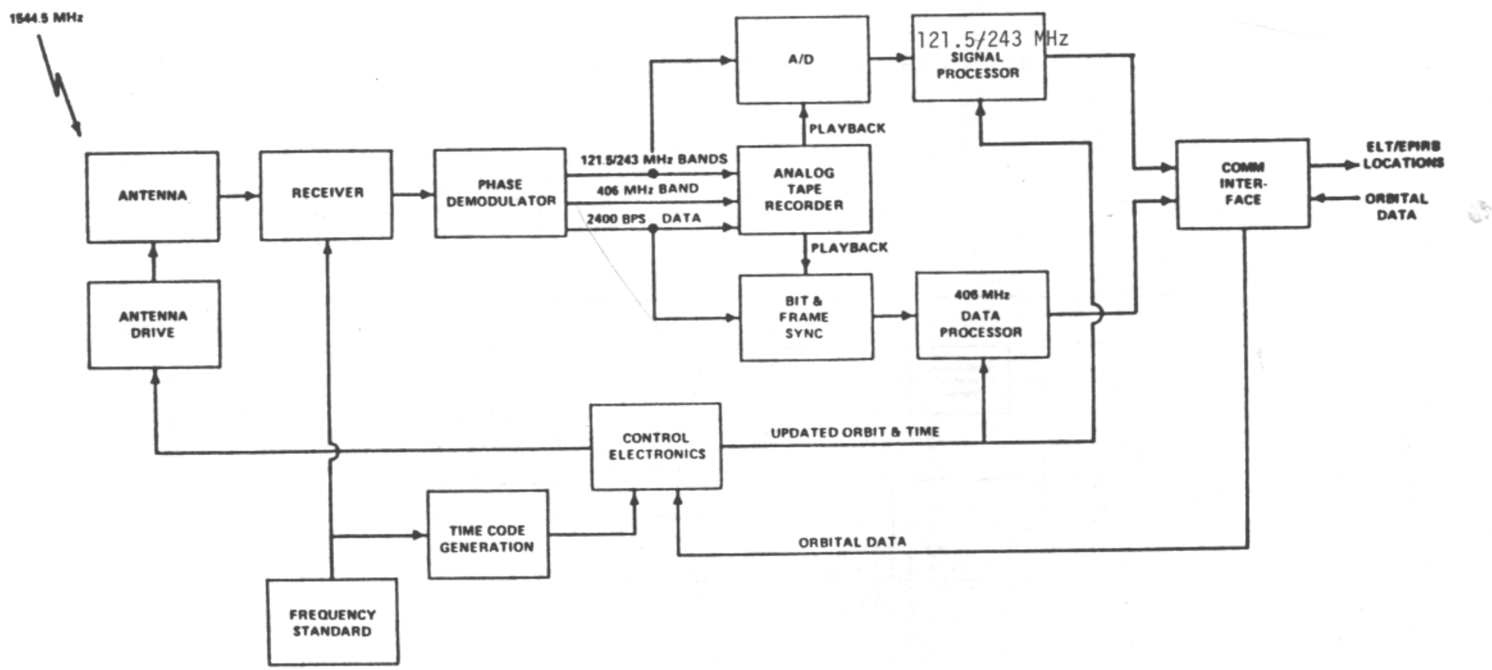

FIGURE 5 TYPICAL SARSAT LUT FUNCTIONAL BLOCK DIAGRAM

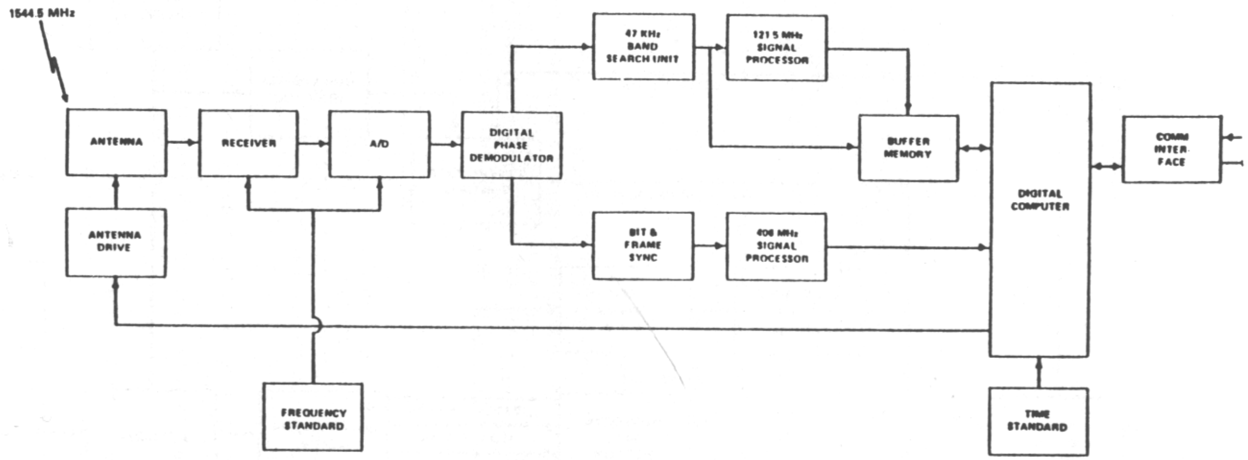

FIGURE 6 **COSPAS LUT FUNCTIONAL BLOCK DIAGRAM**

In Europe, the French MCC forwards location data derived from the Toulouse LUT to those participating countries not having a national LUT.

The COSPAS MCC receives from the USMCC the USSR ELT/EPIRB position information and distress messages obtained from the SARSAT 406 MHz stored data.

Orbital data needed for computing the USSR COSPAS spacecraft ephemeris is provided by the COSPAS MCC to the USMCC. Time calibration data and ephemeris in the form of position and velocity vectors for the SARSAT spacecraft is provided by the USMCC to the COSPAS MCC for use in tracking and position location computations.

COSPAS spacecraft housekeeping data and the Soviet LUT housekeeping data is transmitted to the COSPAS MCC. This data is used for overall COSPAS mission control and as appropriate for co-ordinating with the SARSAT parties via the USMCC.

3. Communications

Current communications arrangements between the Mission Control Centers in the COSPAS-SARSAT system are shown in Fig. 7. These communications are implemented by digital data network, telex, and the Aeronautical Fixed Telecommunications Network (AFTN), as indicated. The communication system is used to exchange the following information:

i) 121.5/243 MHz distress alert and location data;
ii) 406 MHz experimental location data;
iii) satellite status information;
iv) ephemeris data;
v) time and frequency calibration for the SARSAT 406 MHz on board processor;
vi) other information as required.

Although Bulgaria and Finland have joined the COSPAS-SARSAT project, communication arrangements between these countries and COSPAS-SARSAT have not yet been completed, and are not yet shown in Fig. 7.

CONCLUSION

This paper describes the major space and ground segment subsystems of the COSPAS-SARSAT system, the interactions between these subsystems, and the operating modes of the system. Other papers at this conference will provide more details on the design of these subsystems, and on the system performance testing and operational demonstrations and evaluation which have been carried out subsequent to the launch of the two COSPAS and one SARSAT satellites.

REFERENCES

1. COSPAS-SARSAT System Summary dated November 1980.

2. COSPAS-SARSAT Implementation Plan (CSIP).

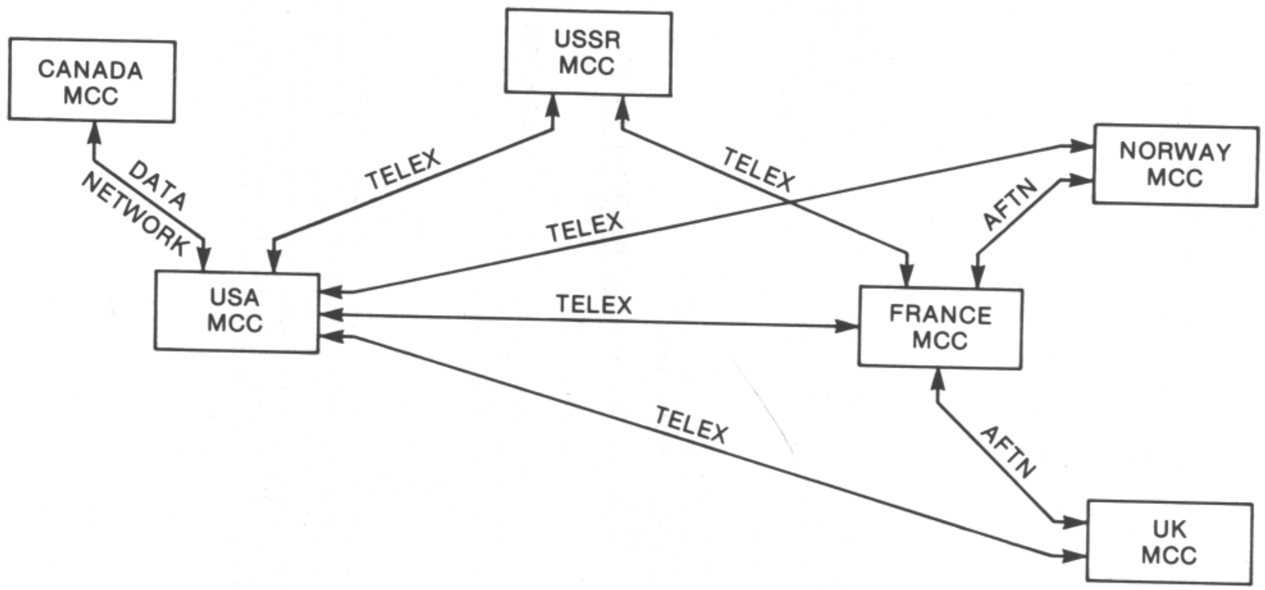

FIGURE 7 **COSPAS - SARSAT MCC COMMUNICATIONS NETWORK**