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CANADIAN ASTRONAUTICS LIMITED'S SARSAT GROUND STATIONS

by

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INTRODUCTION

The involvement of Canadian Astronautics Limited (CAL) in the SARSAT/COSPAS program stretches back over the last decade. Early participation in Canadian feasibility experiments and system design studies led to research into signal processing technology which had been identified as the major technical challenge in the program. CAL's success in developing practical digital processing techniques was a significant factor in the award of contracts to the company by Canada and the United States for the development of the SARSAT/COSPAS ground station, called a Local User Terminal (LUT).

One station has been installed in Canada (pictured in Figure 1) and four in the United States. CAL has also provided the electronics and processing equipment for the French LUT in Toulouse. These six stations have operated reliably since mid-1982 when the first COSPAS I satellite entered into service. They have essentially met or exceeded specifications and have provided the vast majority of all alert data received to date in the course of the SARSAT/COSPAS program.

This paper addresses the evolution of CAL's LUT design in response to a set of extremely demanding functional and performance specifications. It also describes several aspects of LUT/System performance and comments on future approaches to handling multi-orbit, multi-LUT data.

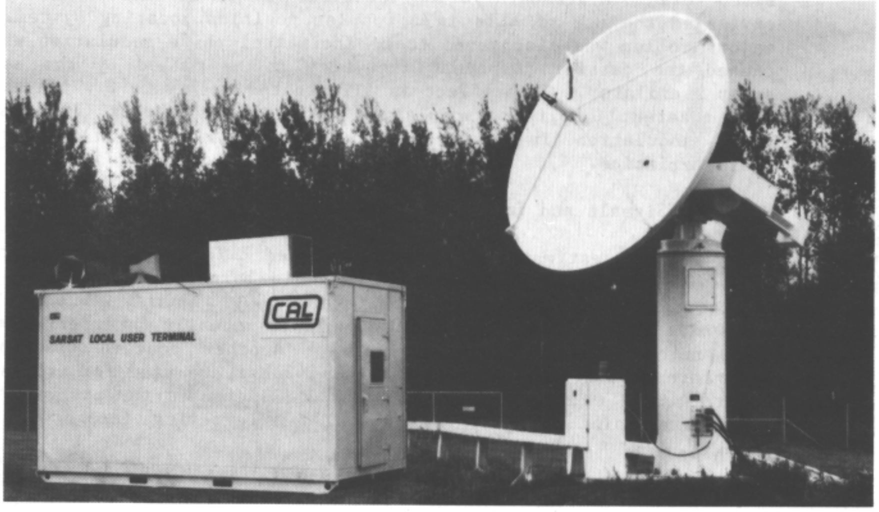


Figure 1 CAL Local User Terminal at Ottawa

THE CAL LUT DESIGN APPROACH

Design Problems

The development of an operational LUT required the solution of many interesting and challenging design problems, particularly those associated with processing of 121.5 MHz and 243 MHz emergency locator transmitter (ELT) signals. The characteristics of the existing 121.5/243 MHz ELTs were a major driving force in determining the LUT system design and posed the following problems:

a) ELT Signal Power

Aircraft type ELTs normally transmit a minimum of only 75 milliwatts of RF power. However it was expected that under realistic operating conditions, external temperature, aging effects and crash damage would likely reduce the effective radiated power from a crash site to a much lower level.

b) Low Signal-to-Noise

The low transmitted power of the ELTs together with an uncertain noise temperature at the spacecraft receiver due to unknown background noise from the earth and other variables produced estimates of signal-to-noise density ratio in the range of 7-56 dBHz. For comparison it is interesting to note that SCPC FM telephony operates at about 55 dBHz and Morse Code transmission requires at least 30 dBHz. The SARSAT specification was set at 23 dBHz minimum for coherent 121.5 MHz signals and a 60 dBHz maximum.

c) Poor ELT Signal Characteristics

The existing 121.5/243 MHz ELTs in service (now estimated to be 0.5 Million world-wide) operate to a variety of fairly loose specifications requiring only that they produce a distinctive audio sweep tone in a standard VHF/AM receiver. These specifications never envisaged the use of ELTs in a Doppler position locating system. A major problem was discovered to be incidental phase modulation which caused the carrier component frequency to be pulled by the audio sweep oscillator. This effect is illustrated in Figure 2 which shows both coherent (amplitude modulation only) and incoherent (incidental phase modulation in addition to amplitude modulation) spectral characteristics.

d) Multiple Signals and Interference

Early studies estimated that with expected ELT population densities and signal activation rates (most signals being false alarms), the LUT would receive up to 10 simultaneous ELT signals. Due to the bandwidth available, these signals would be mutually interfering with one another for most of the time. Another concern was voice interference since both 121.5 MHz and 243 MHz are used for emergency air-to-ground communications. Figure 3 illustrates the problem with a spectral plot of just two mutually interfering incoherent ELT signals.

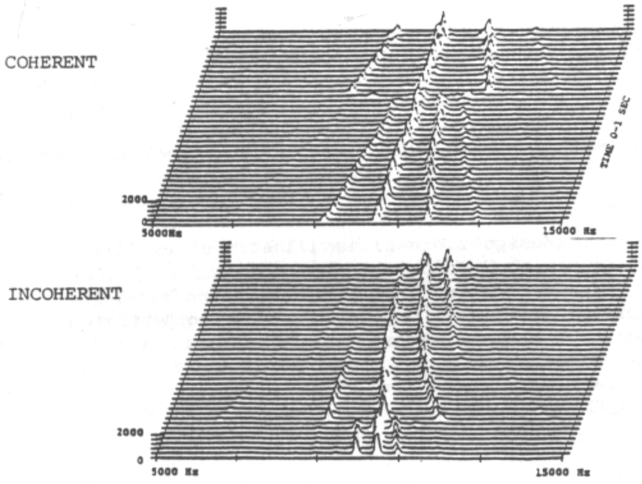


Figure 2 Typical ELT Spectral Characteristics

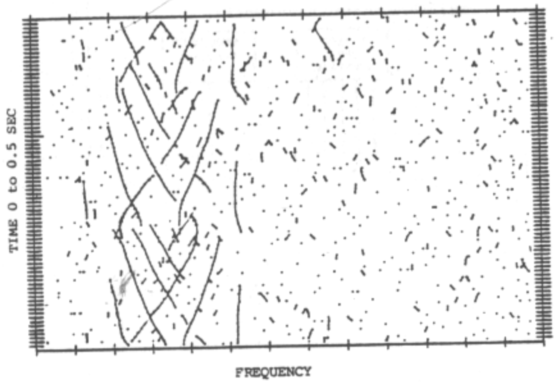


Figure 3 Mutually Interfering Incoherent Signals

The 406 MHz channel promised an improvement in signal format by providing a higher S/N_0, improved accuracy and user identification. On the other hand, the higher accuracy inherent in the 406 MHz system demanded tight control over processing errors, orbit parameters and time clock synchronization.

The basic nature of the SARSAT/COSPAS program also imposed demanding design requirements. As an experimental system, the LUT had to incorporate a great deal of flexibility to adapt to the uncertain signal environment and to permit testing of the technology. At the same time, an essential goal of the program was to provide realistic operational-type performance to allow assessment of the program by user agencies. One of the design goals was to achieve completely automatic operations to minimize staffing requirements and to permit remote transmission of alert messages to a Mission Control Center.

LUT Design Approach

The basic system design approach is illustrated by Figure 4 which is a simplified block diagram of the LUT system.

The RF receiving subsystem is based upon a conventional 3 meter dish antenna mounted on an elevation-over-azimuth pedestal to permit tracking of the low altitude, near polar satellites. Only program tracking is used since orbit parameters and time must always be known precisely for use in position location. Some difficulty was encountered with the RF downlink format. The proximity of the 2.4 Kbps data stream, containing information from the

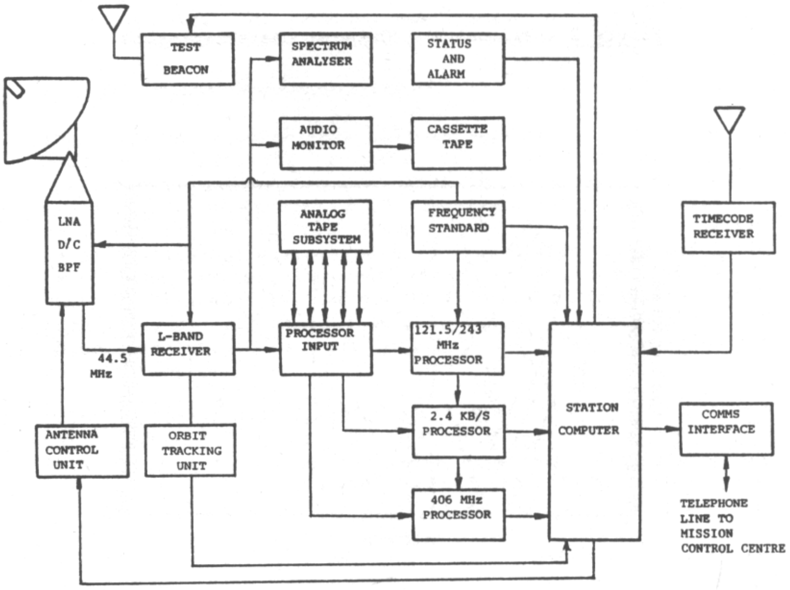


Figure 4 LUT System Block Diagram

satellite-borne 406 MHz receiver/processor, to the main carrier posed a problem in designing a receiver acquisition loop which would reliably lock up on the main carrier under all specified signal conditions. In addition, the 2.4 Kbps digital message format provided some initial problems for proper bit synchronizer lock-up.

It was decided at an early stage to utilize a single general purpose mini-computer for both station control and signal processing tasks. Operation of the LUT is split into two major modes: Real-Time during which Doppler data are generated and stored and, Post-Pass during which data are sorted and position located.

During the Real-Time mode as a satellite passes within view of the LUT, three processors are utilized to generate data. Figure 5 contains a block diagram of the processing functions.

The 121.5 MHz and 243 MHz real-time processing is performed by a commercially available array processor to which data is input directly. It also serves a dual function by operating as a powerful peripheral processor for the main computer during Post-Pass mode. The uncertainties in ELT signal characteristics led to the incorporation of three simultaneously operating detection and measurement algorithms.

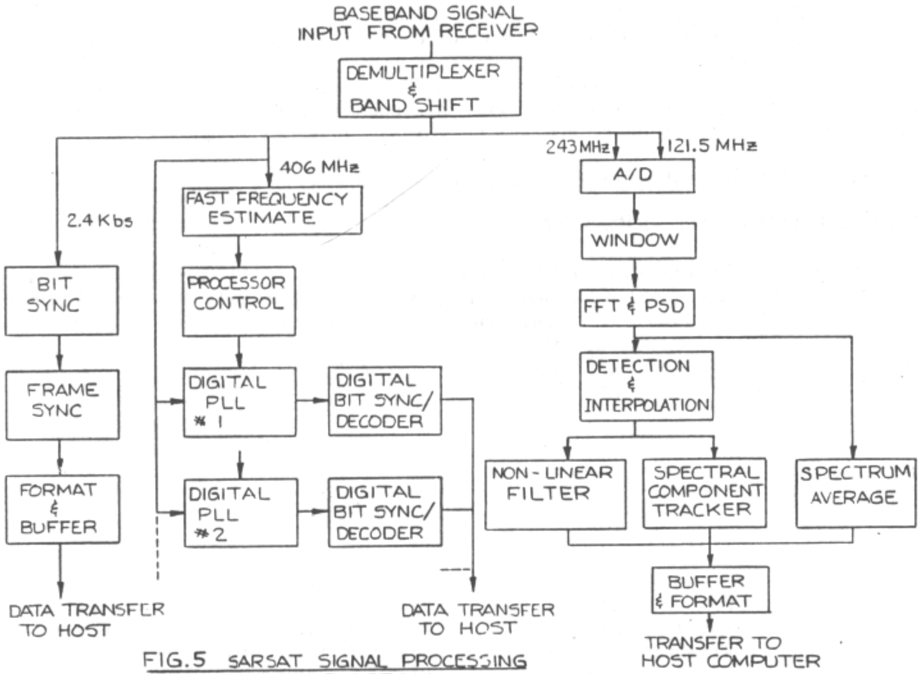


FIG.5 SARSAT SIGNAL PROCESSING BLOCK DIAGRAM

The real-time processing of 406 MHz data contained in the 2.4 Kbps channel is performed by a fairly conventional bit synchronizer, frame synchronizer and data formatter. To process the transponded 406 MHz channel (available only with SARSAT satellites) a special receiver/processor analagous to that contained in the satellites was specially developed. It features two channels (expandable to eight), a Discrete Fourier Transform preprocessor that permits phase lock loop acquisition within several milliseconds, a digital bit sync and message formatter.

Time clocks within the LUT are kept synchronized to within 10 milliseconds of Universal Time by a GOES satellite clock receiver (Western Hemisphere only) or a conventional HF time signal receiver and time code generator.

Orbit parameters can be updated on each satellite pass both by making downlink frequency measurements and by using 406 MHz orbitography beacons in known locations.

Programmatic considerations led to incorporation of an analog tape recorder for archiving and reprocessing of receiver signals as well as for station testing, maintenance and training of operations staff. In addition an audio monitor and spectrum analyzer are provided to assist the operators in monitoring station performance.

A local RF test source is used to perform end-to-end closed loop tests either automatically or under operator control.

A communications interface in the main computer enables alert messages to be transmitted to a remote facility such as a Mission Control Center (MCC) or Rescue Coordination Center (RCC). This link can utilize either a telephone or telex line. Using a telephone link with a computer terminal at an MCC, the LUT can be operated automatically and remotely in an unmanned mode.

Figure 6 is a photograph of the equipment racks.

LUT/SYSTEM PERFORMANCE ASSESSMENT

There are considerable difficulties is assessing LUT performance under realistic operating conditions since ELT signal characteristics are largely undefined and uncontrolled, satellite performance is inherent in the data results, interference is uncontrollable and ELT/Satellite/LUT geometry is always changing. Invariably, attempts to evaluate LUT performance end up as system performance analysis.

Preliminary Performance Assessment

From the operating experience gained in the last 19 months, some general conclusions concerning LUT/System performance can be stated.

a) Sensitivity

Detection of coherent 121.5 MHz ELTs down to a S/N_0 in the range of 17-19 dBHz has been achieved. It is estimated that this corresponds to an effective ELT radiated power of less than a few milliwatts under typical operating conditions.

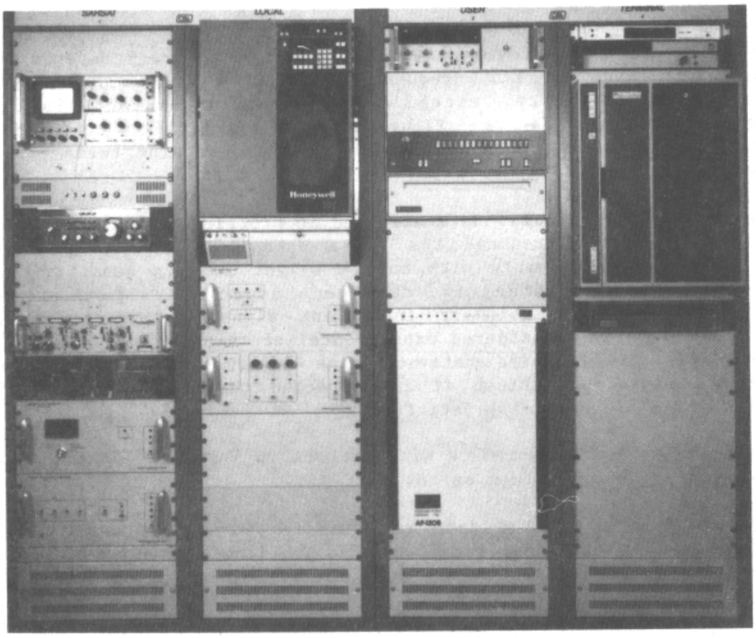


Figure 6 LUT Equipment Racks

b) Multiple Signals

The false alarms which exercise the system provide frequent tests of the system's capability for simultaneous reception and processing of signals. It is not uncommon to receive 6-10 signals in a typical satellite pass and on occasion up to 40 have been recorded.

c) Interference

Interference from a wide variety of sources has been observed on the 121.5 MHz and 243 MHz channels. Nevertheless, the system has proved to be quite robust in tolerating this interference. The data concerning position location information from a continuously operating ELT is spread over a time interval of 5-12 minutes and the LUT has proven itself to be quite capable of withstanding temporary interruptions in the received data.

d) Position Accuracy

Position accuracy is a highly complex subject that deserves a closer look. Initial specifications proved to be either too simple and vague or unsuitable as to the practicality of making real measurements to verify them.

Position Accuracy

Aside from the LUT performance itself, position accuracy depends on many other parameters such as ELT frequency stability (drift and coherence), ELT/Satellite/LUT geometry, satellite transponder characteristics and interference conditions. Figure 7 illustrates the Doppler data obtained during a simulated satellite pass showing results from each of the three processing algorithms.

In practice, the filtered data are used in preference to the spectrum average data since this reduces the noise data considerably and produces accurate frequency measurements with only a slight loss in sensitivity. The spectral component tracker is designed especially for extracting difficult-to-measure non-stationary incoherent signal components at higher S/N_0 levels and is still considered experimental at this stage. However it has been found that the filtered data contains information on many types of incoherent ELT signals, although it is suspected that a certain fraction of incoherent signals are not being detected.

Analysis of system performance with respect to position location accuracy requires several essential steps as follows:

a) normalization of the data with respect to major system parameters such as cross track angle and ELT coherence which can have major effects on accuracy. Figure 8, for example, illustrates the relative expected error as a function of cross track angle. ELT/Satellite/LUT mutual visibility constraints (coverage limits) can also reduce the data interval which impacts accuracy significantly and frequency stability of ELT signals has a major effect on a position location accuracy.

b) generation of sufficient data to produce statistically significant results.

c) interpretation of results with respect to properly defined expectations.

Most attempts based on collection of operational-type data fail to address one or more of the above steps. However, since such data is seemingly most relevant to the interpretation of operational experience of the system there is a great temptation to accept the results at face value. Such analysis does not reflect the performance of only the LUT but also includes effects due spacecraft, ELTs, system orbit geometry and data handling and interpretation at the MCC.

Position location analysis often specifies the accuracy as 20 km, one sigma and this requires some interpretation. Theoretical considerations of position location accuracy for moderate values of cross track angle and reasonable constraints on other system parameters can represent the position errors in latitude and longitude as random variables each having a separate Normal distribution. Their joint probability is given by a bivariate Normal distribution.

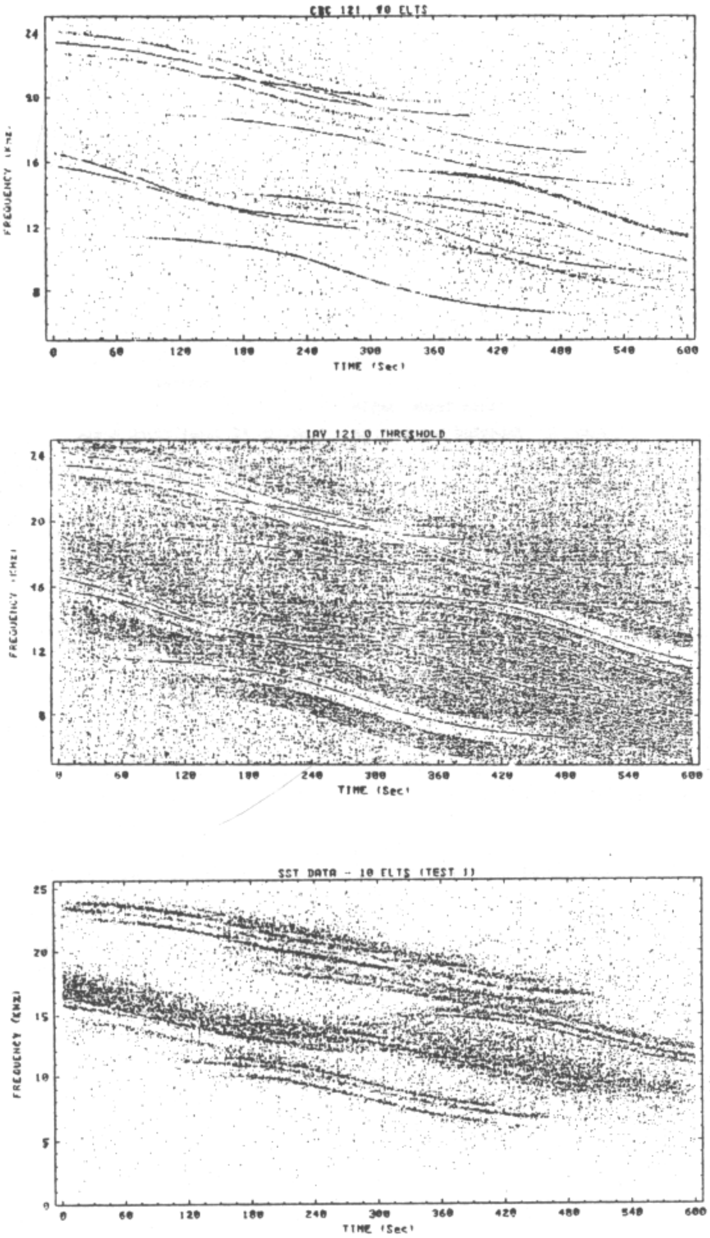


Figure 7 Typical Doppler Data Plots

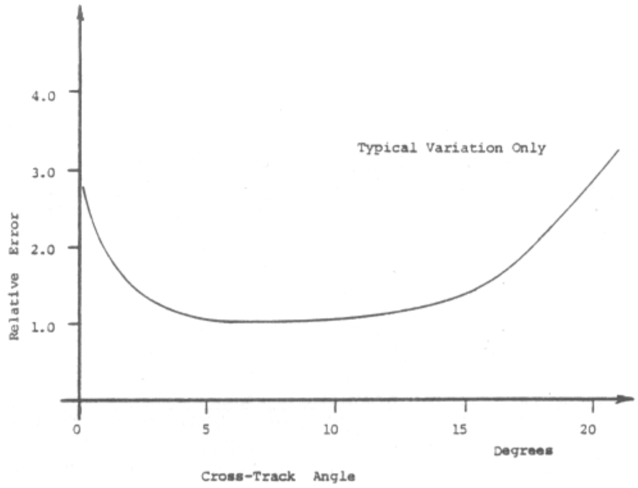


Figure 8 Expected Accuracy as a Function of Cross-Track Angle

Assuming, for moderate cross track angles, that the standard deviation of the error in each direction is identical, and the errors are unbiased, the probability function for the one-dimensional radial error is given by the following Rayleigh distribution:

$$P(r) = \frac{1}{\sigma^2} r e^{-\frac{1}{2} r^2/2\sigma^2}$$

r = radial error

σ = standard deviation for the error in each direction

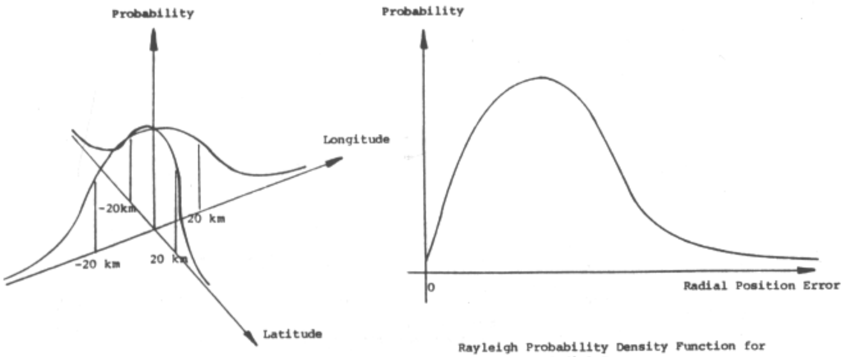
Integrating to obtain a cumulative probability function for radial error less than R gives the following:

$$P(r < R) = 1 - e^{-R^2/2\sigma^2}$$

Using a standard deviation of 20 km for the error in each direction the probability that the radial error is less than 20 km (a circle of 20 km radius) is 0.394.

If on the other hand, the criterion is that the radial error be within an area of less than 20 km in each direction (a box of 40 km on each side) the probability is simply the multiplication of the two unidimensional one sigma probabilities and equals 0.466.

Figure 9 illustrates the probability functions discussed above. It is not possible to define a one sigma value for the single sided probability density function for radial error since its mean value is non-zero. However, using 20 km one sigma for the probability density function in each axis, the expected value (average) of the radial error is 25 km. Alternatively, if the average radial error is constrained to 20 km, this implies that 54.4% of the data will be less than 20 km in error.



2 Dimensional Normal Probability Density Function

Rayleigh Probability Density Function for Radial Error

Figure 9

System Performance Results

A number of attempts have been made to make a preliminary assessment of system performance with respect to position accuracy. One set of tests was performed at the LUT in Ottawa during 1983. Controlled test signals from frequency stable sources as well as signals from temperature stabilized ELTs were transmitted from the LUT site. The results are plotted in Figure 10 for data covering all cross track angles. Also plotted are results of operational experience from actual incidents in both the United States and Canada occuring during part of 1983. The number of points in the operational data is large enough to expect reasonably significant results but it is quite difficult to verify that data has been properly associated with each event. Nevertheless, as a global perspective of system performance, the results are useful as a preliminary indication.

The data in Figure 10 have been truncated to errors less than 100 km. The U.S. data actually indicated approximately 9% of the data over 100 km error.

The Canadian data were broken down into data between cross track angles of 2-18 degrees and data outside that range. The results are contained in Figure 11 and, as can be seen, the data outside the 2-18 degree range are considerably poorer as is expected from theoretical considerations of ELT/Satellite/LUT geometry.

An alternative way of viewing the data is to plot the statistics of only the closest single pass solutions generated for each event. These data are plotted in Figure 12 together with the total data set for reference. Although the closest solution is not always the first alert message generated, the best solution is usually generated within 48 hours of the initial orbit pass.

Much more work will be required in the future to characterize system performance with respect to the major parameters affecting accuracy.

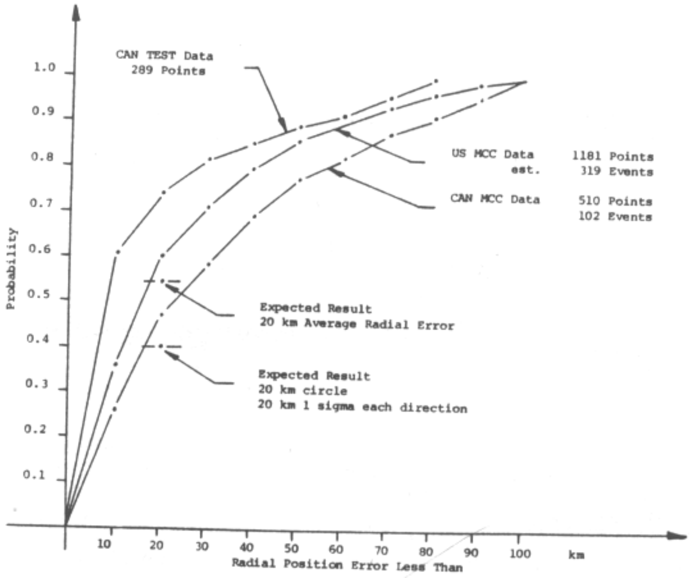


Figure 10
System Accuracy Performance
Test and Operational Data

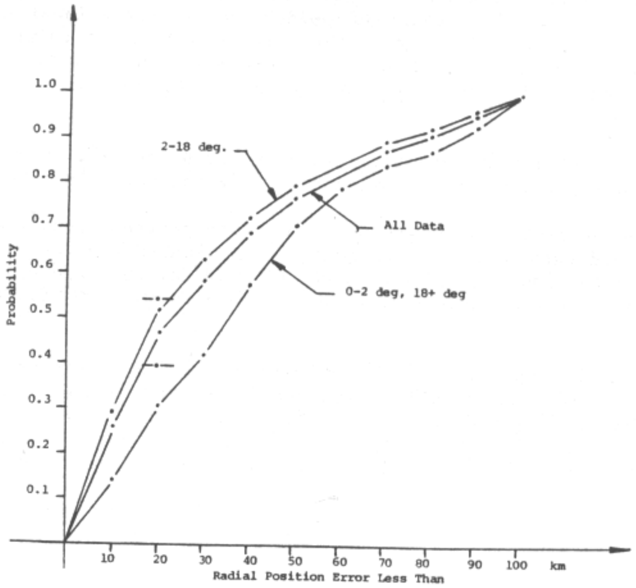


Figure 11
System Accuracy Performance - Cross Track Filtered

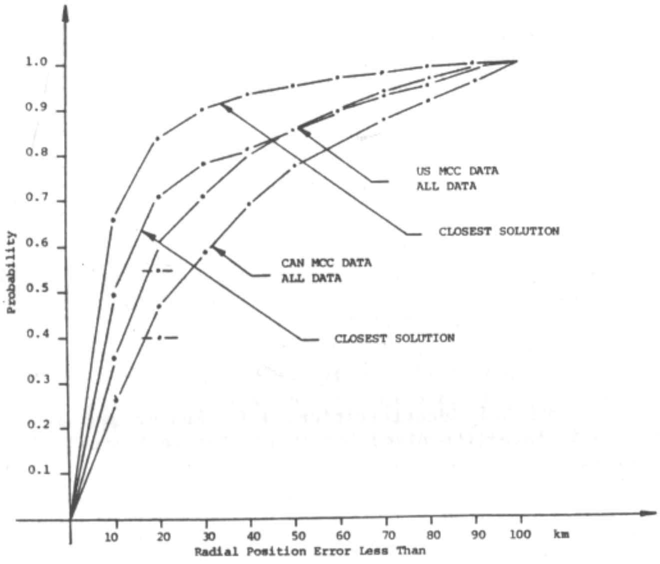


Figure 12
Closest Solution Performance Data

Future Directions for Handling Alert Data

One of the major problems now being addressed is the method of handling the large number of alert messages that result from an incident in a multi-satellite, multi-LUT environment. In a relatively short time (12-36 hours), a single event can easily generate 10-20 alert messages. Even from a single orbit pass, multiple alert messages can be produced as a result of sidebands.

The unexpected flood of data in the past has sometimes forced the MCCs to accept only the first alert message that is generated and to discard the rest. Obviously the first position received may not be the most accurate. However, by combining the data with a properly designed merge routine, even better accuracy should be achievable than is possible on a single pass basis.

An essential step prior to data merging is the correct association of alert messages resulting from a single ELT. Reference 1 reports on work being done by CAL to develop characterization software for 121.5/243 MHz signals. Merge capability using Kalman filter techniques is already built into the current LUT software and with some minor modifications should be able to deliver greatly improved accuracy. In a multi-LUT environment, the merge function should ideally be incorporated into the MCC.

CONCLUSIONS

The CAL SARSAT/COSPAS LUT has been successfully developed in response to a variety of challenging technical and program requirements. The design is now relatively mature and capable of working in an operational environment.

The performance so far has exceeded expectations. An on-going program of research and development is producing refinements that will continue to provide improved performance.

ACKNOWLEDGEMENT

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