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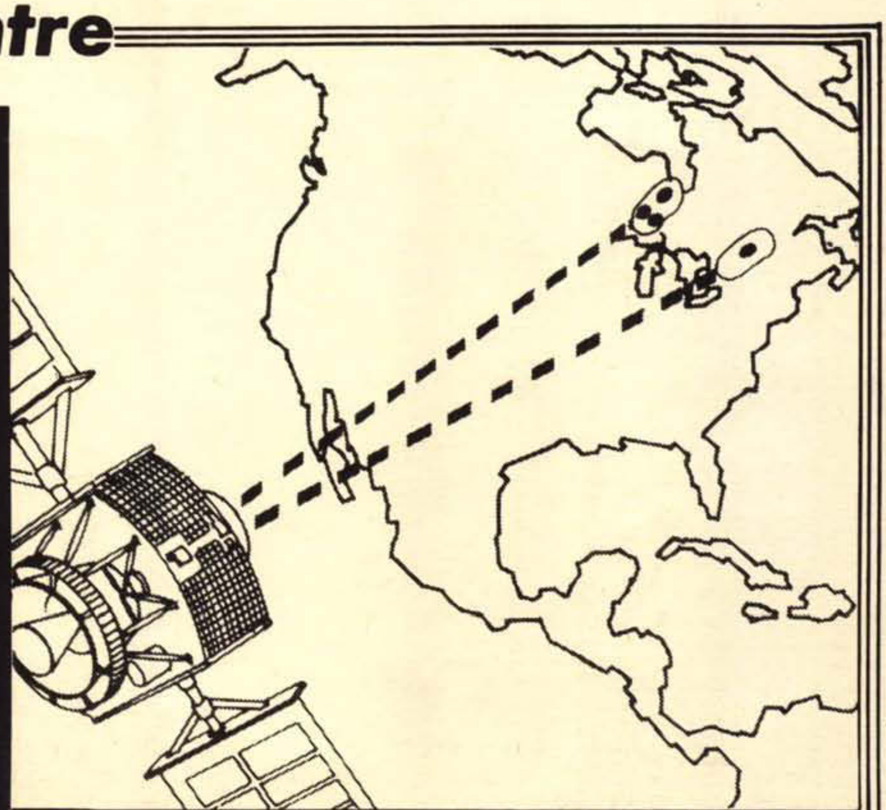

CENSAR

CENTRALIZED SYNCHRONIZATION AND RANGING

EARLY OPERATIONAL EXPERIENCE WITH A NEW TDMA SYNCHRONIZATION SYSTEM THROUGH CTS

by

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Department of Communications
Ministère des Communications

CRC TECHNICAL NOTE 682

OTTAWA, OCTOBER 1976

COMMUNICATIONS RESEARCH CENTRE

DEPARTMENT OF COMMUNICATIONS
CANADA

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SUMMARY

The work is part of a communications experiment entitled, "Time-Division Multiple-Access Synchronization", CTS F-1-2, using the Communications Technology Satellite (CTS), also known as Hermes, and Canadian earth stations. When time-sharing a communications satellite in a TDMA mode, each station transmits information in bursts which must be accurately synchronized, so that bursts do not overlap and so that gaps between bursts are minimized. This experiment has the prime objective of demonstrating that a novel synchronization technique, called CENSAR (CENtralized Synchronization And Ranging), is feasible and advantageous.

This technical note documents Phase I of the experiment conducted in June, July and August 1976. Very accurate, centrally-controlled earth synchronization has been demonstrated and, hence, very efficient TDMA systems based on CENSAR are feasible. Furthermore, the accurate synchronization method inherently provides ranging measurements which enable determination of the spacecraft orbit.

On-going work on observed data is expected to yield refined results. Phase II of the experiment is in preparation and has the main objective of operation in separated spot beams.

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ABSTRACT

A unique TDMA concept is described. The implementation of the concept as an experimental package on the Communications Technology Satellite (CTS) is briefly discussed. Early operational experience at IF and RF is presented. CENtralized Synchronization And Ranging is demonstrated as feasible. Tests are on-going and the final results will be reported in the literature.

1. INTRODUCTION

Multiple access is defined as the shared use of a satellite transponder. Three types of multiple access are possible (Figure 1) and hybrid forms also exist. The first method is analoguous to frequency division multiplex in which each user is assigned a unique frequency band. Since this process is analogue in nature, care must be exercised to minimize intermodulation products. This implies that the satellite transponder must operate in the linear region, i.e., in a backed-off mode, thus the full power cannot be utilized. In addition, practical filtering dictates a guard band between each user channel so that the full transponder bandwidth is also not fully utilized.

In the second method, analoguous to time division multiplex, the full power and bandwidth is allocated on a time shared basis to the subscribing ground stations. Both FDMA and TDMA are suitable for commercial broad-band communication.

The third method of multiple access employs spread spectrum techniques or code division in which unique codes provide the required orthogonality. CDMA is not very efficient but is robust in that successful operation is possible under very noisy conditions. In addition various coding techniques permit high security. CDMA thus has application in low capacity, low-power environments and in military and other secure communications.

In TDMA there is a need for synchronization to ensure no overlap of signal bursts received at the satellite on the one hand, and minimization of the inter-burst guard time for maximum utilization of the expensive facility on the other hand (Figure 2). The problem of synchronizing many stations to a remote facility is compounded by the drift motion of the satellite within a volume of space typically bounded by ± 0.1°EW, ± 0.1°NS, and ± 0.1% in altitude (Figure 3). The largest dimension of this volume is approximately 500 μs. round trip delay and the satellite position in that volume can fairly readily be predicted to within ± 1 microsecond although better accuracy is possible with more sophistication.

For compatible operation with terrestrial telephony the frame length for a TDMA system is usually constrained to multiples of 125 μs., the sample rate of a 4 kHz voice channel. Each frame contains the bursts from each subscribing station (Figure 4). Each burst has an associated guard time to provide for the uncertainty involved in the particular synchronization process. Since each receiving station has to acquire and lock to the burst directed to it, a preamble is required in each burst. The preamble contains codes to permit clock and bit timing recovery in addition to certain housekeeping information. The length of the preamble varies typically between 45 and 128 symbols (see bibliography of reference [1]) where the symbol duration - depending on the satellite bandwidth - is typically between 15 and 30 nanoseconds.

The link signal to noise ratio is determined by the various antenna G/T and EIRP. In some cases this may be insufficient to provide an acceptable error rate and it may be necessary to resort to coding the message to improve the fidelity. Convolutional coding techniques are generally used in this situation and it is thus the practice to provide a post-amble equal to the code constraint length to clear the buffer. A post-amble may also be required for demodulator quenching.

A figure of merit for a TDMA system is the frame efficiency [1] which is defined as the ratio of potentially useful time in a frame to the total frame duration - see Figure 5. Thus, for maximum efficiency, it is necessary to minimize both the guard time and preamble length.

2. CENSAR

2.1 INITIAL CONCEPT (POMA)

The initial concept (Process Oriented Multiple Access) was proposed by R. deBuda [2] and was applicable in global beam applications. In this concept three stations each sent a short burst to the spacecraft and measured the round trip delay; the bursts were encoded with this information. Every station in the network receives the three ranges and can thus compute the position of the spacecraft as the intersection of three spheres.

2.2 CENSAR CONCEPT

For spot-beam applications the above process is not possible since, in general, a station in one beam cannot receive its own transmission or those of stations in the same beam. The CENSAR concept overcomes this problem by having a central control station transmit to all stations in the network information bursts containing its own uplink delay and the uplink delays of three ranging stations. The three ranging stations, not necessarily in the same spot beam, transmit back a time mark signal at the appropriate time derived from the control station information which is thus continuously updated. In this situation the spacecraft is at the intersection of three ellipsoids of rotation (Figure 6).

The real time solution of the set of three simultaneous triquadratic equations is very messy but, fortunately, the problem can be linearized with a very small error [3] permitting any station to accurately calculate its range to the satellite to within an expected uncertainity of less than 20 ns [4]. In addition there is sufficient information in the control station synchronization bursts to permit clock-and bit-timing recovery without the corresponding portion of the preamble required in other systems. It is anticipated that a frame efficiency of approximately 90% for 30 accesses can be achieved with this system (Figure 7). This is comparable to the efficiency of Intelsats' 750 μs. frame proposal and apparently superior to other commercial, voice-oriented TDMA proposals. In many cases however sufficient or up-to-date information is unavailable in the literature for a true comparison of frame efficiency to be made and, in addition, some schemes do not lend themselves to this descriptor [1].

Prerequisites for the CENSAR approach are a knowledge of the exact location of each station in the system. The geometrical considerations impose certain constraints on the relative locations of the ranging stations and control station. Total equipment delays must also be known and propagation effects must be considered [4,6]. In addition, for exact physical location of the satellite (not absolutely necessary for synchronization purposes), the delay through the spacecraft should also be known (Figure 8).

2.3 ADVANTAGES AND DISADVANTAGES

The CENSAR system permits passive acquisition and synchronization of any station at any time after the three ranging stations have achieved delay lock. The associated stations are thus relatively simple and the number of stations can be very high. On a high power, SHF spot-beam satellite such as CTS, small diameter earth station antenna can be used. Thus, in combination, these two factors offer the opportunity of a centrally controlled and switched medium-route facility.

The central control station is responsible for all the processing and measurement and is therefore fairly complex. For reliability reasons the central control station and the three ranging stations will require back-up facilities; these latter facilities however could also supply the required diversity for the deep fades possible at SHF [5]. Finally, central control may not be acceptable when several jurisdictions are involved.

3. IMPLEMENTATION OF SYNCHRONIZATION SUB-SYSTEMS

For the purposes of the current experiment the synchronization sub-systems for one control station, three ranging stations and one other station which can act either as a ranging station or as an associated station (thus providing a system check) were specified at Communications Research Centre (CRC) and manufactured by Canadian Marconi Company (CMC). Each unit comprises one 25 cm. deep by 48 cm. wide shelf (Figure 9). In addition, a PDP 11-40 computer drives the control terminal and an 11-10 the associate terminal. In practice the function of this latter device could easily be performed by a micro-processor but, for experiment purposes, the flexibility offered by a computer was deemed desirable.

A simplified block diagram of the control terminal (CT) (Figure 10) shows the general principle of operation. Using a correlation receiver the distance measuring equipment performs three distinct measurements termed FINE, BIT and FRAME on the two-hop delay CT-S/C-RT-S/C-CT. In inverse order, the FRAME measurement determines the correct 125-microsecond interval from the end of transmission from an RT, the BIT measurement determines the correct 32.7 nanosecond interval within that frame and the FINE measurement has a resolution of 0.95 nanosecond, the basic unit. The total variable portion is 2^{24} basic units or 16 milliseconds. A constant portion provides the required total measurement capability of about 500 milliseconds.

The control sentence generator transmits a 31-bit 2ϕ PSK 65.536 Mb/s burst at the beginning of each frame. These bursts are either coded as a "mark" or, in complemented form, as a "space". 16 marks or 16 spaces form a control bit, eight such bits form a control byte or word and 28 control bytes constitute a control sentence which is updated every cycle of 640 milli-seconds. The information contained in this sentence includes the four 24-bit delays T_1+T_1, T_1+T_2, T_1+T_3 and T_1+T_4, the rate of change of these delays (equivalent to the relative velocities of the satellite with respect to the four stations) plus control/status and order wire. The processing gain obtained from this approach yields a computed error rate of 10^{-24} in the equivalent 500 b/s information channel.

A matched filter in each ranging station (Figure 11) extracts cycle, frame and bit timing plus the appropriate range information and transmits a time-mark consisting of 1000 short bursts of maximal-length sequence at the beginning of each frame in the quarter allocated to that station (255 bits used currently but 31 bits should be adequate in future applications). The bursts are 2ϕ PSK at half the rate of the control station transmission and are transmitted at a low level.

The associate station (Figure 12) includes the functions of a ranging station and, in addition, a facility for passively computing its delay to the satellite from the information in the control sentence and transmitting a high level message burst (PN sequence) in synchronism. This permits measurements of the interburst spacing at the control terminal as a check on predicted guard time.

4. PRELIMINARY TEST RESULTS

Tests at IF and RF using a simulator and test range were conducted during the hardware-software interfacing and equipment calibration period. The actual interface selected for this experimental equipment was demonstrated to be sound and only minor variations are foreseen for a commercial system. One additional feature that is under consideration is a real time measurement of local atmospheric conditions relayed back to the control station in order that refraction corrections can be made. This could reduce the required guard time by up to 2 ns. [6]. A comparison plot (Figure 13) of the measured RF range and the range predicted from local refractivity measurements for the RF test range shows excellent correlations in spite of the fact that the atmosphere was only monitored at one end of the range and that the range crosses a river valley (Figure 14) which could affect the propagation profile.

Measurements on the satellite have thus far been limited to ranging only since all of the ground stations are located in the same area during terminal check-out. Thus the large triangle required for fine resolution of the satellite position is not available. Ranging using both the CENSAR technique and the sine-tone technique used by the TT&C facility show good correlation. However, (1) the receive antenna for these two facilities are over 2 Km apart, (2) it is electrically impossible due to equipment limitations to calibrate each facility on the same RF test range, and (3) certain equipment delays are either unknown or difficult to measure or predict. The residual (constant) discrepancy of approximately 50 nanoseconds is thus not particularly significant.

An example of the measurement capability is a direct real-time plot of the satellite range. Shown is an extract from the plot (Figure 15) when the satellite went through the maximum range.

In the start-up mode, simultaneous acquisition of all three ranging terminals typically takes less than 20 seconds. This is accomplished with no a priori knowledge of the delays. Subsequent access by any other associated station is instantaneous. A commissioning period during installation of an associated station is required to refine the station coefficients. The software at the present time assumes the range to be predictable for a period of one and a half minutes after a ranging station has dropped out for any reason. This period is however quite flexible. It is intended to cover contingencies such as cut-over to emergency power supplies, switching to redundant equipment, etc.. The hold-over period should also permit a transfer to the back-up ranging station in the event of a complete failure or deep fade, but the impact of such hit-less switching on the software has not been addressed at the present time.

All data will be stored on tapes and retained for possible future processing should this be required. An orbit perturbation study using this data is an adjunct to the CENSAR experiment.

Several minor problems during the early commissioning period of the spacecraft, the various ground station antenna and the CENSAR equipment illustrate the experimental nature of this work. In combination these problems have generated two month's slip in the original schedule and demonstrated the need for further tests and possible modifications to cope with unforseen operational limitations and procedures. This slip should not, however, affect the bulk of the CTS experiments.

5. OPERATIONAL EXPERIENCE

Experience has shown that signal levels, absolute and relative, must be adjusted and controlled. There is presently provision for automatic level control (ALC), but the present design is not adequate. We have designed a gated ALC for each measurement loop and expect that this will allow wide dynamic operating conditions. Two of the measurements (BIT, FRAME) are made with a threshold crossing detector, which is sensitive to level changes. The threshold level is automatically controlled to fall in the optimum region.

Although not a major problem, nominal frequencies are required to be adjusted to allow for differences in station up- and down-conversion frequencies and to compensate for transponder frequency offset. Experience to date shows that the processing bandwidth of 80 kHz is adequate.

The use of a mini-computer with in-house programming has proved very valuable. Due to the experimental nature of CENSAR and flexible operational requirements, software changes are being made even now. Full monitoring of the experiment data is possible and a small command structure permits instant reconfiguration of the set up.

Along with such flexible operations at central control, a communications network including all remote stations is highly desirable. The CTS ground stations all have two-way voice capability which is usually available during experiment operations. Otherwise, switched telephone calls are also used.

6. CONCLUSIONS

A new concept for TDMA synchronization has been implemented and preliminary testing has demonstrated that the concept is valid. There is every reason to believe that the experimental system will successfully demonstrate that CENtralized Synchronization And Ranging with accuracies of the order of 10 to 20 ns. is feasible and economic (Figure 16). The testing continues for the month of June and possibly July and a second phase of tests is scheduled for next year.

Since the presentation of the information included in this Technical Note the full triangulation ranging and synchronizing have been demonstrated with the three ranging stations situated in London, Quebec City and Rouyn-Noranda. Good agreement between measured and calculated associate terminal range has been demonstrated and the commissioning strategy is under study.

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4. Nuspl, P.P., N.G. Davies, R.L. Olsen, *Ranging and Synchronization Accuracies in a Regional TDMA Experiment*, International Conference on Digital Satellite Communications - 3, Kyoto, November 1975, pp. 292 - 300.

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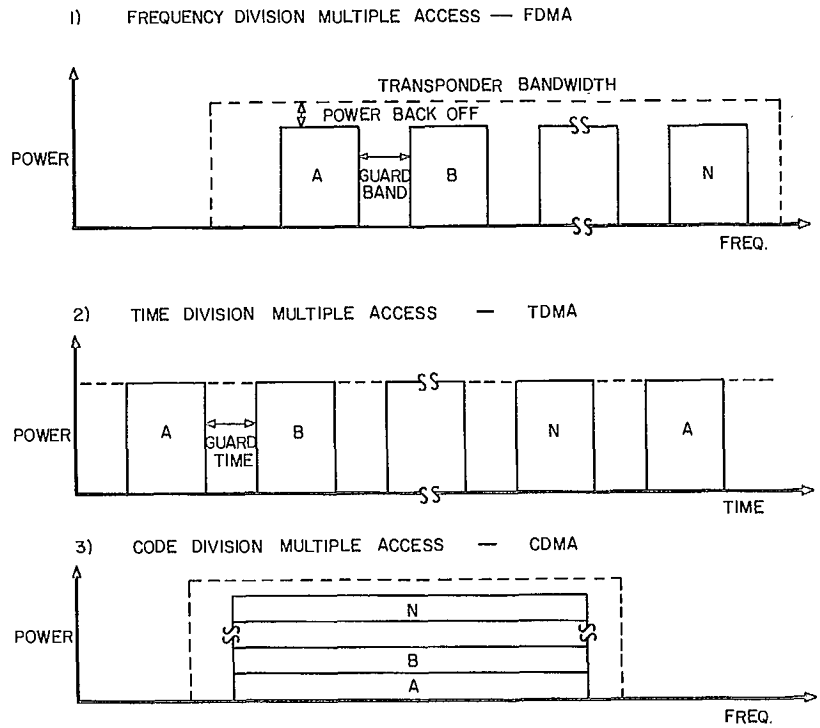


Figure 1. Multiple Access Techniques

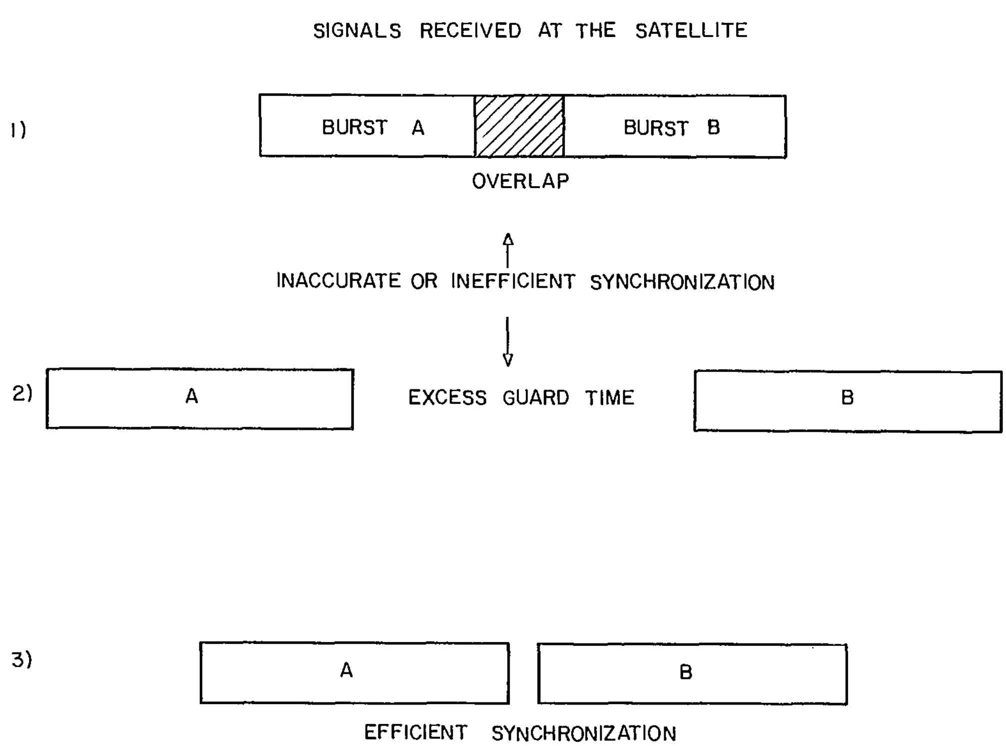


Figure 2. Effect of Synchronization

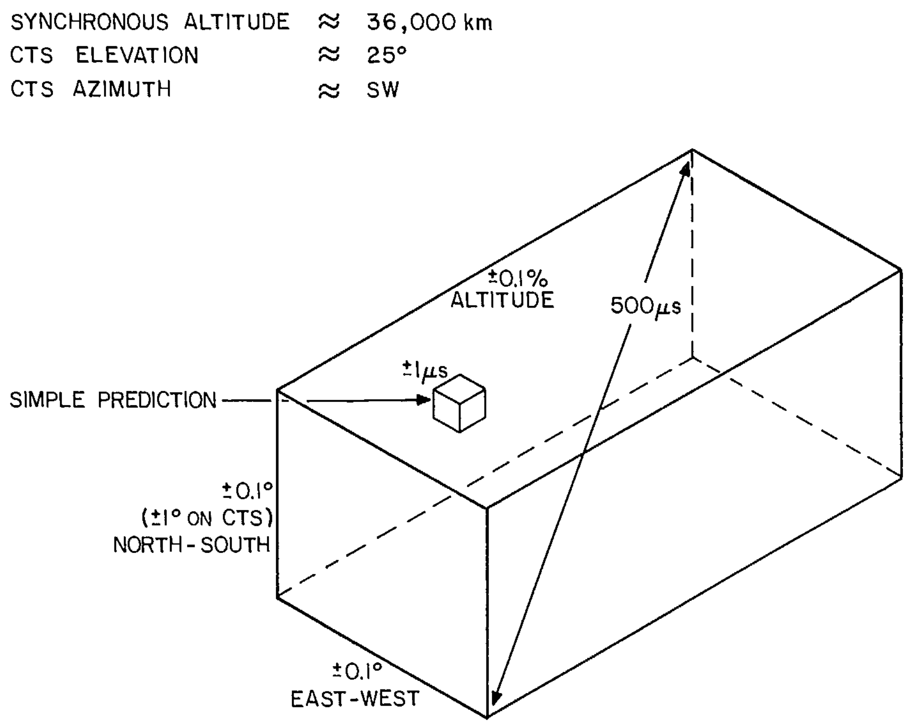


Figure 3. Geosynchronous Satellite Drift Volume

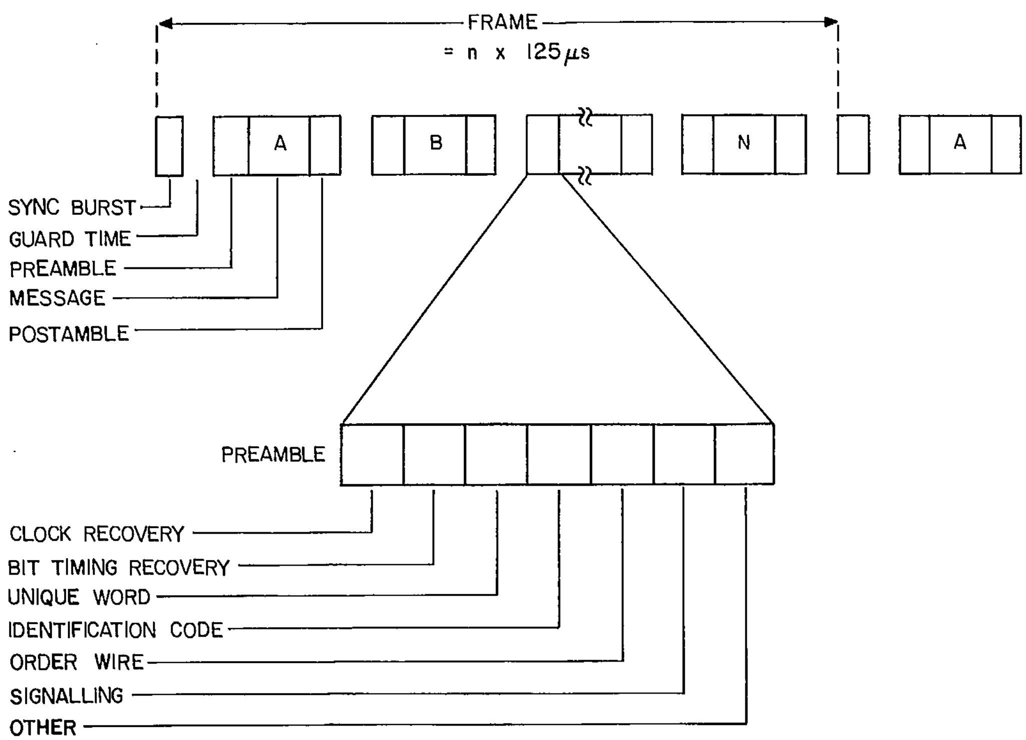
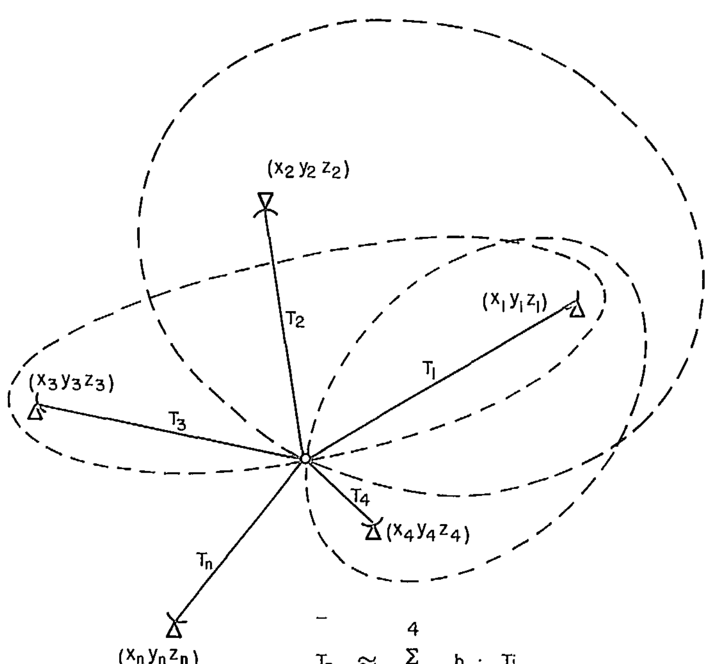


Figure 4. Typical Frame Format

$$\epsilon = 1 - \frac{S + N\,(G + P + Q)}{F}$$

ϵ	=	Frame efficiency			
S	=	Length of Sync. burst	(μs)	–	function of sync. process
N	=	Number of accesses		–	function of network
G	=	Guard time	(μs)	–	function of sync. process
P	=	Length of Preamble	(μs)	–	function of sync. process
Q	=	Length of Postamble	(μs)	–	function of link carrier to noise
F	=	Length of Frame	(μs)	–	function of service offered

Figure 5. Definition of Frame Efficiency



$$\bar{T}_n \approx \sum_{i=1}^{4} b_{ni}\ T_i$$

$$b_{ni} = f\,(x_i y_i z_i\, x_n y_n z_n)$$

Figure 6. Determination of Satellite Position (Plan View)

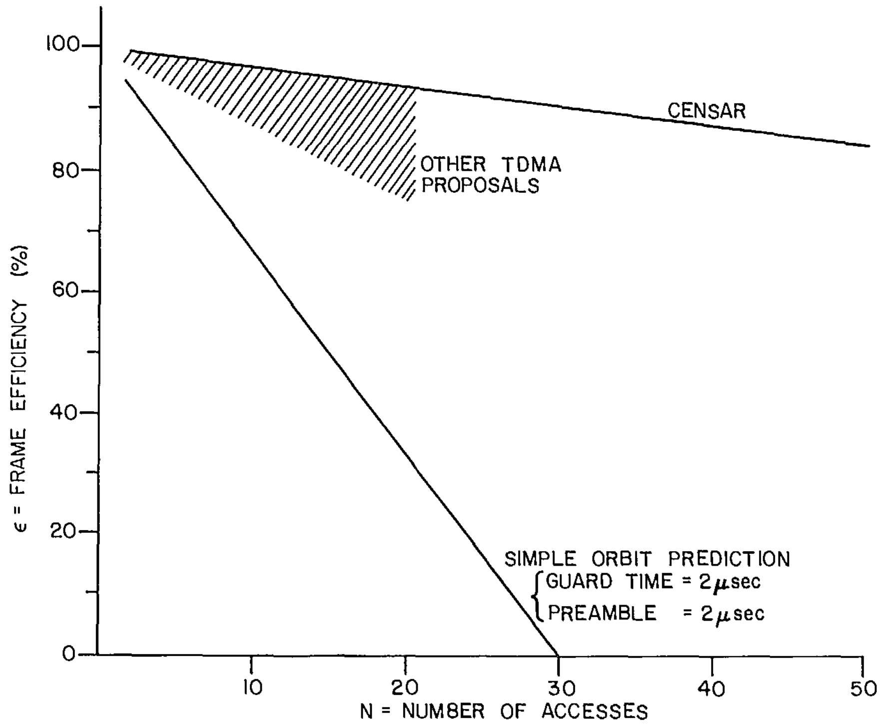


Figure 7. Frame Efficiency of CENSAR

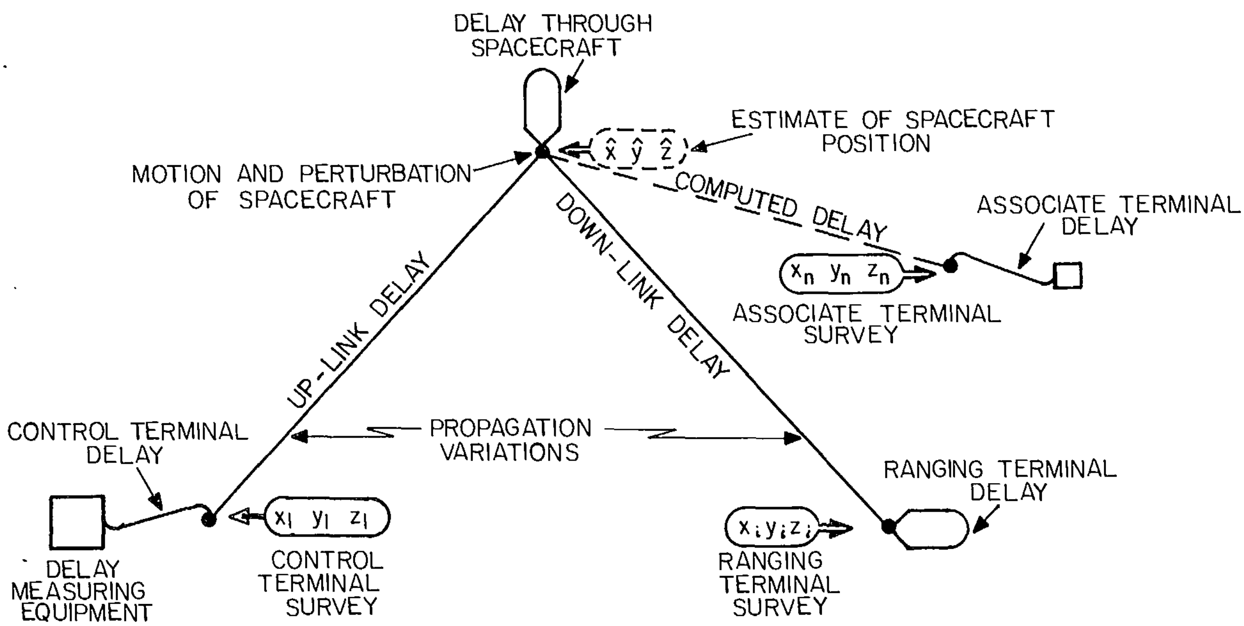


Figure 8. Factors in Distance Measurement and Passive Synchronization

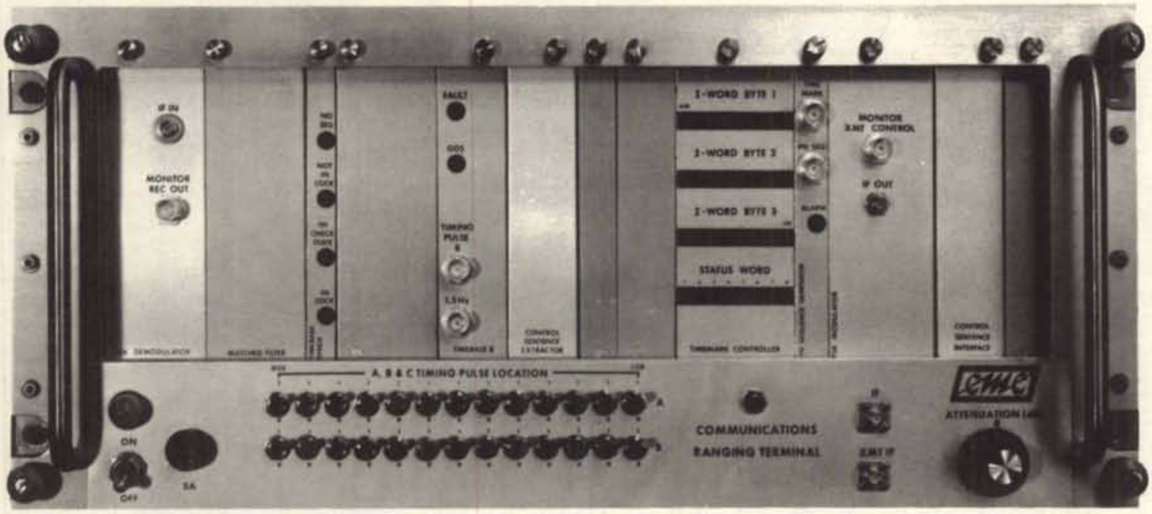


Figure 9. Typical Front Panel Layout

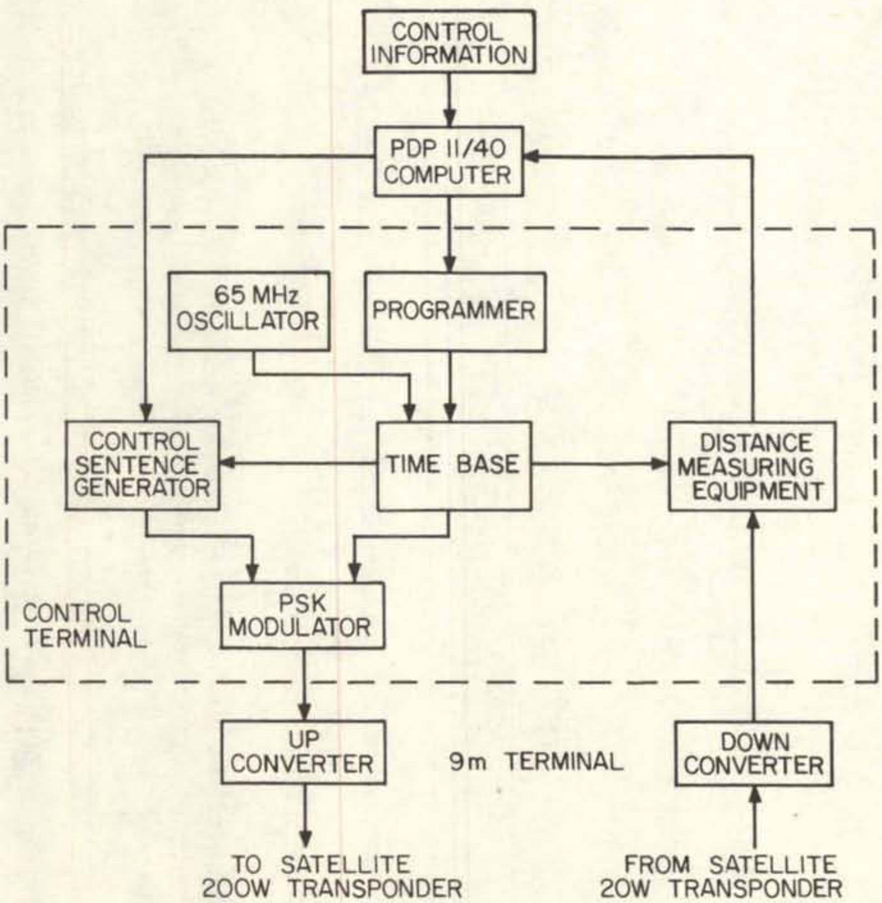


Figure 10. Control Terminal Block Diagram

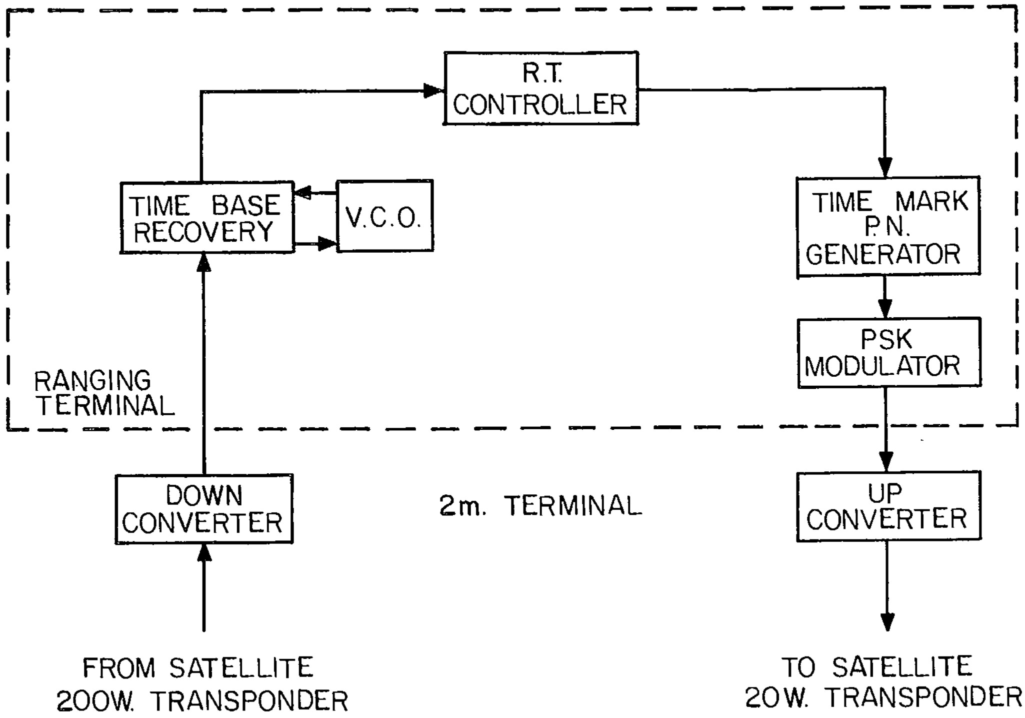


Figure 11. Ranging Terminal Block Diagram

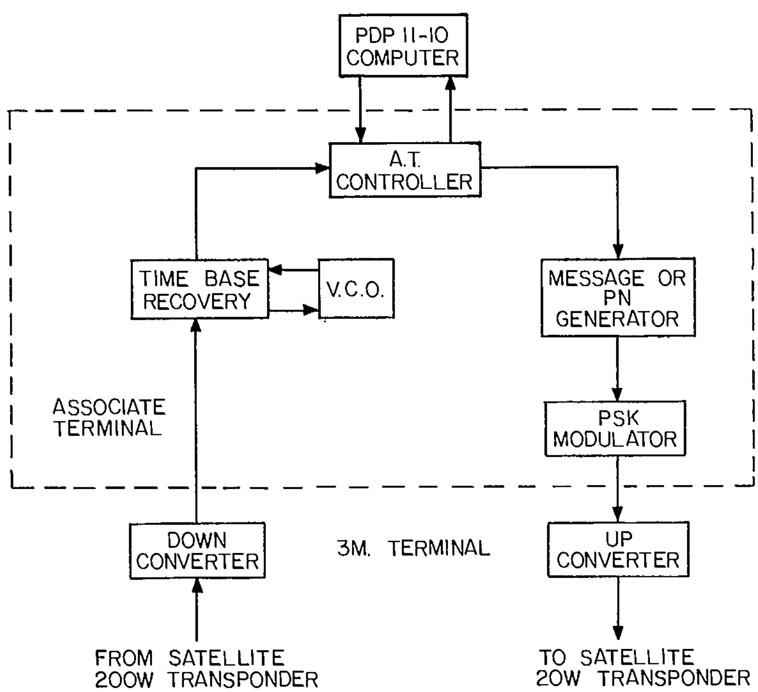


Figure 12. Associate Terminal Block Diagram

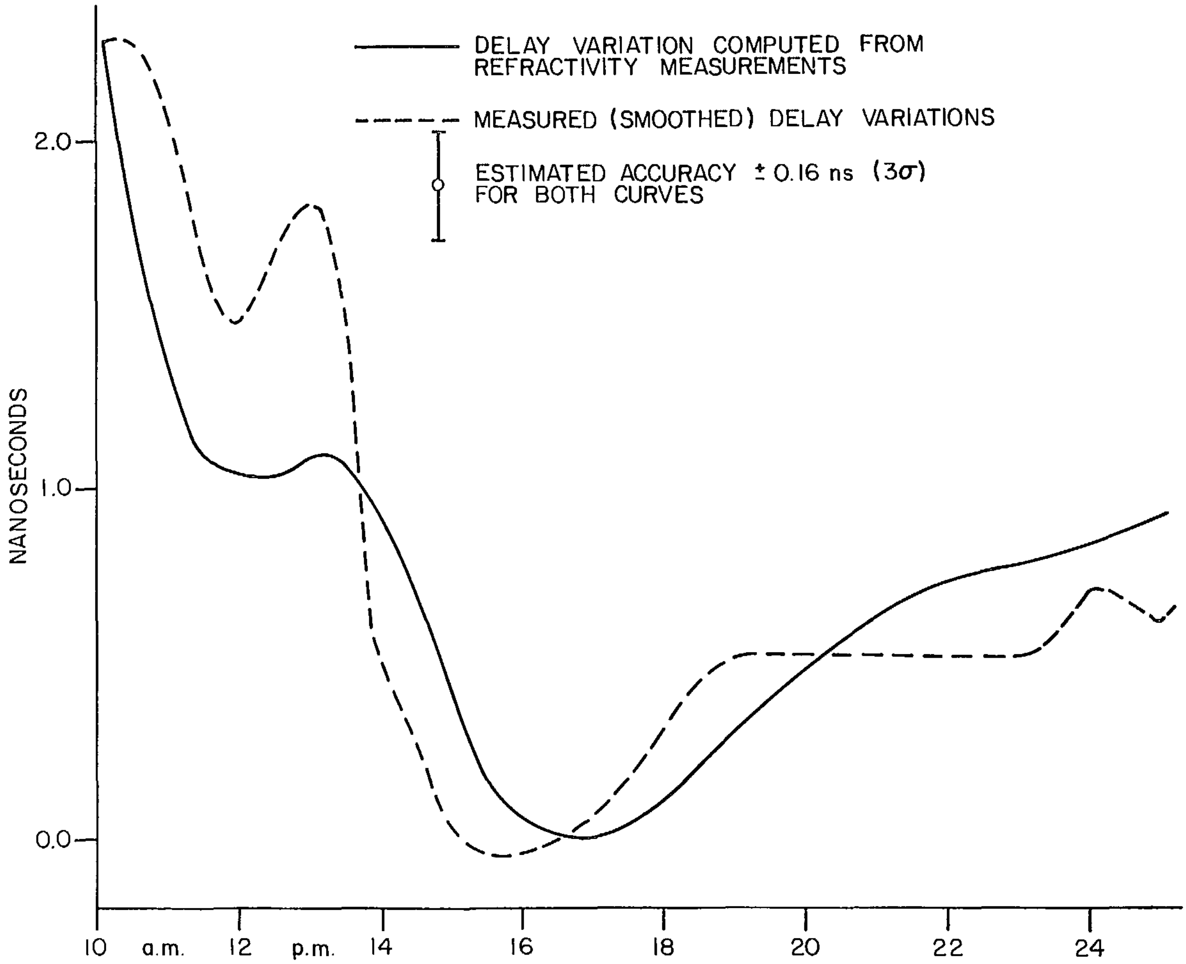


Figure 13. Effect of Propagation

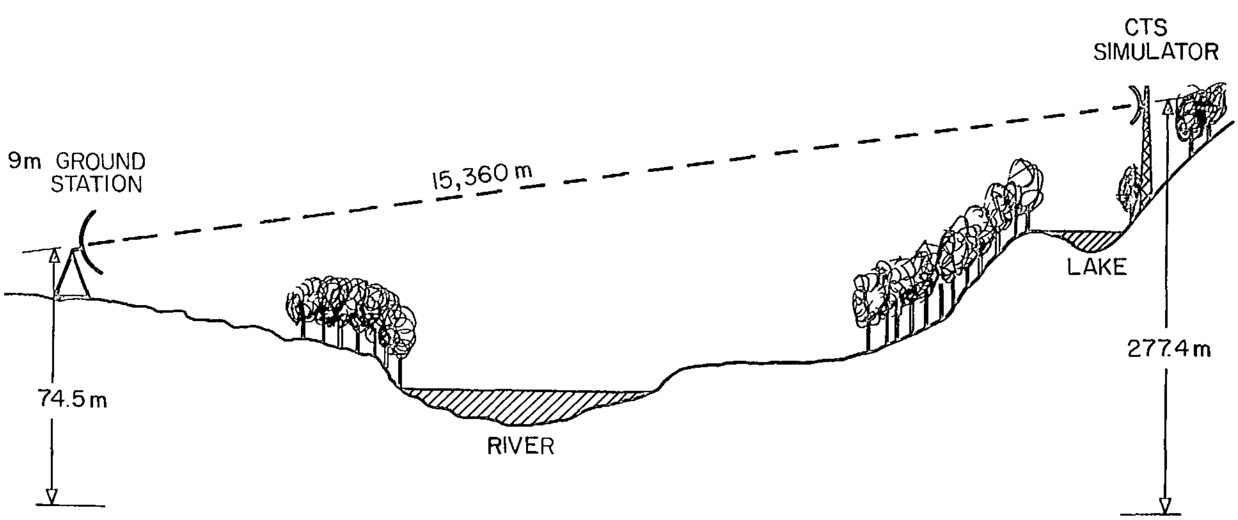


Figure 14. CRC Test Range

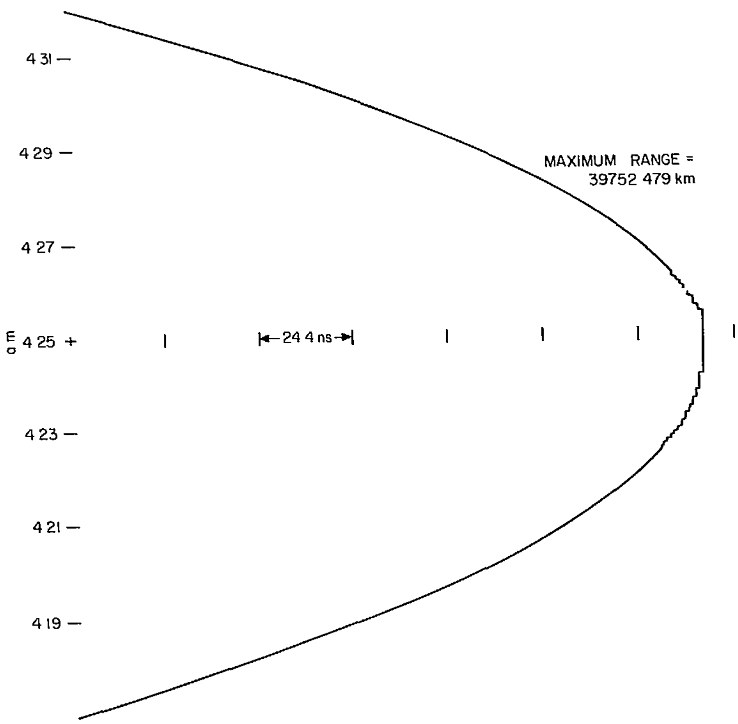


Figure 15. Real Time Plot of Fire Measurement Portion

HIGHLIGHTS

1)	Range Resolution	< 1 ns.
2)	Guard Time	< 20 ns.
3)	Initial Simultaneous Acquisition of 3 Ranging Stations	< 20 s.
4)	Subsequent access by another station	Instantaneous
5)	Number of accesses	Up to 200
6)	Applicable to advanced satellite technologies	

e.g., – spot beam
– satellite switching
– multiple satellites with intersatellite links

7) Relatively economic

Figure 16. CENtralized Synchronization And Ranging

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8. ABSTRACT:

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9. CITATION:

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