# PTTI SYSTEMS ON THE EASTERN TEST RANGE

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## Abstract

**The Eastern Test Range (ETR) is a missile and rocket testing facility available to military and commercial users for the launching and testing of space vehicles. The ETR provides over 4,000 nautical miles of tracking coverage of these vehicles from four major land–based tracking stations and one shipboard tracking station. At each station there are a myriad of Precise Time and Time Interval (PTTI) requirements that must be met. The most demanding requirements are: synchronization accuracy to the United States Naval Observatory (USNO) Master Clock to 100 nanoseconds, frequency accuracy of $1 \times 10^{13}$ (Tau = 1 day), no single point of failure and continuous (24 hours per day, 365 days per year) PTTI operation. This paper will update a similar paper delivered at the Eightennth Annual PTTI Applications and Planning Meeting and will describe the techniques employed to meet all of the ETR's PTTI requirements. Philosophical notions such as range PTTI service is much like a highly reliable utility sevice, synchronization from GPS should not be overemphasized, and gradual corrections are preffered to step corrections will be presented.**

## BACKGROUND

Figure 1 is a functional ESMC organization chart, showing only that which is germane to this paper. The principal users of PTTI on the ETR are the launch sites at Cape Canaveral Air Force Station (CCAFS) and the downrange tracking stations at Jonathan Dickinson Missile Tracking Annex (JDMTA), Antigua, Ascension, and on the USNS Redstone. There are other ETR sites and instrumentation which require PTTI systems. Refer to Figure 2 for a map of the ETR locations. The ESMC agency responsible for sustaining engineering and modernization of the Eastern Test Range (ETR) is the Deputy Commander for Systems Development (ESMC/DV). ESMC/DV in turn directs the Center Technical Services (CTS) contractor to implement the required engineering services to ETR systems, which include Radar, Telemetry, Command Destruct, Optics, Communications, and Precise Time and Time Interval (PTTI). In most cases the CTS contractor provides systems engineering services to procure and develop systems utilizing equipment available from industry. The CTS contractor engineers are also responsible for the design, development, fabrication, installation, and testing of unique equipment which is not available from the private sector.

In order to satisfactorily accomplish its mission and to support Range customers with their programs, the ETR has numerous PTTI requirements. ETR PTTI systems are often regarded as highly reliable and accurate utility services which are required to operate twenty four hours a day, 365 days a year.

Requirements range from providing a single Time-of- Year display in an aircraft control tower, to a highly reliable system with over 160 output PTTI signals and synchronized within 250 nanoseconds to the DoD Master Clock, to redundant Range Safety systems where no single failure (PTTI systems included) can cause both systems to fail. Each PTTI system is designed to meet both the dependability and accuracy requirements of the using system. To accomplish these objectives in the most cost effective manner, a hierarchy of "Clocks", each closely synchronized to the next higher level, has been established. Thus each user of PTTI on the ETR will benefit from high quality Clocks without incurring the expense of building independent timing systems.

## SYNCHRONIZATION HIERARCHY

Each ETR facility, where PTTI services are provided, is traceable to the DoD Master Clock. The Range Clock, collocated with the Station Clock at the Cape, is synchronized and traceable to the DoD Master Clock to within 250 nanoseconds. Each Station Clock is synchronized and traceable to the Range Clock to within 500 nanoseconds. Site requirements determine the synchronization accuracy and traceability of each Site Clock to its local Station Clock. Refer to figure 3 for a composite synchronization diagram.

To achieve and maintain the required synchronization accuracies, time interval and frequency comparisons are made among all local timekeeping equipment (Cesiums, Digital Clocks, Micro Phase Steppers, Time Signal Generators, etc.) and outside reference sources (GPS, LORAN-C, Portable Clock, etc.). These frequent comparisons provide the basis for the thorough understanding of how each equipment behaves relative to all others. Thus when one component fails to compare as expected against all others, whether that component be a Cesium, Micro Phase Stepper, or GPS Receiver, its contribution to the local time scale is discounted and minimized. Consequently no "out of spec performance" from a single equipment or system should cause failure to meet an ETR accuracy specification.

The ETR has resisted adopting GPS as the one and only PTTI system of the future. While GPS is arguably "the best" synchronization source to UTC (DoD MC) and its recent history has demonstrated sub 50 nanosecond (RMS) accuracies to the DoD Master Clock, there have been occasions when UTC (DoD MC) – UTC (GPS) has exceeded 400 nanoseconds. When Selective Availability (SA) is fully implemented, the RMS value of UTC (DoD MC) – UTC (GPS) is expected to be approximately 300 nanoseconds. Thus ETR PTTI systems requiring better than 100 nanosecond accuracies employ Cesium ensembles and synchronization information from Portable Clocks, GPS, LORAN-C, and various other PTTI radio frequency (RF) sources.

## RANGE CLOCK

The Range Clock is located in the CCAFS PTTI Center, Range Control Center, Cape Canaveral Air Force Station, Florida. The Range Clock serves as the reference for all time and frequency on the ETR. Its major components are four high performance Cesium Beam Frequency Standards, three Micro Phase Steppers, seven Digital Clocks, two Global Positioning System (GPS) Receivers and two LORAN-C Receivers. The three Micro Phase Steppers are utilized to correct the output frequencies from three of the Cesiums so the resultant frequency is more nearly that of the DoD Master Clock. The Digital Clocks provide time derived from each frequency source (Cesium and Micro Phase Stepper). The GPS and LORAN-C Receivers provide frequent time transfer information from the DoD Master

Clock, used in conjunction with Portable Clock data to derive the long term corrections employed by the Micro Phase Steppers.

## PTTI VAULT

Figure 4 is a photograph of the PTTI Vault where much of the Range Clock equipment is installed. This is an environmentally controlled area where the equipment is installed on low frequency shock mounts and the temperature and humidity are closely monitored. Currently temperature is controlled to approximately one degree Celsius. Chart Recorders are used to show the phase relationships of the various frequency sources.

The performance history of a frequency standard can be used to predict its near future time only when it has been continuously operated in a controlled environment and without adjustments. For this reason extensive precautions are taken to insure that the environment is constant and power is always present to all equipment in the PTTI Vault. No adjustments are made to the oscillators, and frequency corrections are made using only the exacting digital features of the Micro Phase Steppers.

The entire PTTI Vault is operated from an Uninterruptable Power Source (UPS). In the event the UPS does fail, all equipment is battery backed–up for approximately 48 hours.

## PTTI MONITOR AND CONTROL SYSTEM

Figure 5 is a photograph of the PTTI Monitor and Control System and various PTTI receivers. The computer based monitor system automatically collects time interval measurements made among the various equipments in the PTTI Vault, the PTTI receivers, and the local Station Clock equipment. Measurements are made daily at 1800 UTC, upon restoration of ac power, and upon operator demand. Provisions are also available to set up a "Special Measurement Set" where several measurements can be made more frequently and/or at specified times. The operator may also enter narrative information pertinent to the operating PTTI on the ETR into a "Daily Log" file. Currently, this system is used only to collect and store data, and to assist the operators in determining the Micro Phase Stepper values.

Figure 6 is a diagram of the PTTI Monitor and Control System, as it is now and as it will be when completed. PTTI Monitor and Control Systems will be installed at each Station Clock. They will be networked together in a star configuration with the CCAFS controller at the center of the star. This design will allow the CCAFS controller to retrieve PTTI measurements from all the downrange Station Clocks, schedule GPS and LORAN-C common view measurements between Station Clocks, and effect adjustments to the Micro Phase Steppers. The CCAFS controller software will derive the "Paper Clock" for each Station Clock and output, via the IEEE-488 Bus, Micro Phase Stepper values so the resultant frequency from each Cesium/Micro Phase Stepper pair is corrected to be syntonized to that of the DoD Master Clock. The first "Paper Clock" ensemble algorithm will be similar to the one being used at the USNO Time Service Alternate Station, Richmond Heights, Florida.

Currently PTTI Monitor and Control Systems are installed at the Cape PTTI Center, CCAFS and JDMTA. A partial extension of the CCAFS PTTI Monitor and Control System was implemented at the Antigua PTTI Station Clock several years ago. Until recently the only sub 10 microsecond time transfer system available was LORAN–C. Because Antigua is in a fringe reception area for LORAN–

C the correct cycle tracking is unreliable. The best way to insure proper timing at the unmanned Station Clocks, is to validate its continuous operation by taking frequent time interval measurements between various timing sources after the correct time had been validated by a Portable Clock. At Antigua, automated time interval measurements between the Station Clock Cesium Beam Frequency Standards, Time Signal Generators, LORAN-C Receiver, and GPS Receiver are taken every 6 hours, and transmitted back to the CCAFS PTTI Center. Operators at CCAFS analyze the received data and develop Micro Phase Stepper values used to slowly slew the Antigua Time Signal Generators to be closely synchronized to the Range Clock. One set of measurements is made simultaneously with measurements made at the Range Clock (1800 UTC) so the Antigua Station Clock synchronization is verified using LORAN-C and GPS common view techniques.

Plans will expand the PTTI Monitor and Control System to include automated verification of Site Clock performance. Since unmanned ETR Site Clocks now are driven by Synchronized Time Code Generators, synchronized to the local Station Clock, it has become apparent that Site Clock timing errors (due to loss of input signal, transmission noise, equipment failures, etc.) can go unnoticed indefinitely. Thus it is imperative that a means to monitor the performance of Site Clocks be developed. The Site Clock Monitor System will monitor all the Site Clocks at a given Station (CCAFS, Antigua, Ascension) and provide status information to each PTTI Monitor and Control System. To verify the proper functioning of the Site Synchronized Time Code Generator, an IRIG B120 signal, output from the Generator, will be sent to a digitally controlled switch located at the local Station Clock. A microcomputer will switch select a specific Site Clock IRIG B120 to be decoded for Time-of-Year data and control function data (encoded status bits from the Site Clock). The Site Clock IRIG B120 will also be examined to determine if its phase (time offset) is within predefined values. Any discrepancies will be transmitted to the CCAFS PTTI Monitor and Control System, where operators will be alerted to the potential problems and can initiate responsive action.

## CCAFS STATION CLOCK

Since both the Range Clock and the CCAFS Station Clock are collocated in the same facility, the CCAFS Station Clock obtains its sense of time and frequency from the Range Clock. Two Time Signal Generators are synchronized to the Range Clock and are driven from the corrected (Micro Phase Steppered) frequencies of the Range Clock. These Time Signal Generators are capable of producing all IRIG serial time codes and decade pulse repetition rates (1 pulse-per-day through 100 kpps). In addition they generate various non-standard time codes which are required by customers not yet totally in compliance with the IRIG standards identified in Document 200-70, published by the Range Commanders Council. Like outputs from each Time Signal Generator are compared in a Coincidence Monitor Panel, where any synchronization difference greater than 2 microseconds or disagreement in code content activates an audible alarm and illuminates an identifying lamp to indicate which signal pair is in disagreement. Outputs of the manually selected Time Signal Generator are conditioned and then provided to Range Communications for distribution to authorized users within a forty mile radius.

All Station Clocks are scheduled to have these redundant Time Signal Generators and associated Coincidence Monitors replaced with modernized equipment. The new equipment will employ triplicated Time Signal Generators and a Coincidence Monitor which will automatically select the best Time Signal Generator for distribution to PTTI users. Additionally the modernized distribution equipment can sense an output amplifier failure and will select an alternate output amplifier for distribution. The

CCAFS Station Clock is scheduled to receive this new equipment when the Station Clock is relocated to a new facility in the summer of 1991.

Another major PTTI system located at the CCAFS Station Clock is the USNO Monitor system. This system employs the Data Acquisition System (DAS) described by the Automation of Precise Time Reference Stations (PTRS) paper presented by Paul J. Wheeler during the Proceedings of the Fifteenth Annual PTTI Applications and Planning Meeting. With the USNO Monitor System, the Naval Observatory obtains GPS data from a Naval Research Laboratory GPS Receiver and time interval measurements made between the Station Clock, the PTTI Vault Cesiums, and the LORAN-C Receiver 1 pps signals. The Naval Observatory compares readings from this system with those simultaneously made against LORAN-C at their site in Washington D.C. and provides a real-time time transfer measurement utilizing common-view LORAN-C techniques. The results of the USNO data analysis is transmitted to the Range Clock for use in coordinating and steering its local time scale.

## CCAFS SITE CLOCKS

Timing signals are distributed to outlying instrumentation sites (Site Clocks) via standard telephone cable plant, video cables, and a local UHF Radio system. Most signals are transmitted over 19 AWG or 22 AWG telephone cables in bipolar pulse form to the Site Clocks where the signals are reconstructed into standard dc level shift or amplitude modulated formats. Newer Site Clocks now employ Synchronized Time Code Generators which input IRIG B120, compensate for transmission delay, and output required IRIG standard codes, decade repetition rates (1 pps through 1 kpps), and decade frequencies (100 Hz through 100 kHz). The Synchronized Time Code Generators also provide "Flywheel" operation through input signal code errors and loss of input signal. Thus site timing signals are uninterrupted and accurate even if there are momentary input faults.

Site Clocks within a forty mile radius of the CCAFS Station Clock can also obtain time via the UHF Radio system. Timing Signals from the Station Clock are Time Division Multiplexed and transmitted 1 millisecond early on a 1750 MHz carrier. Site Clocks with receiver and decoder equipment, demultiplex and output the required signals "on time" (within the 1 microsecond resolution of the delay compensation equipment). This system is now over 20 years old and will be replaced by a new upgraded UHF system. The new system will use the Micro Phase Steppered frequencies from the PTTI Vault to synthesize the 1750 MHz carrier. IRIG B120 and 1Mhz, from the Station Clock, will amplitude modulate the RF carrier. Thus all UHF signals are transmitted coherently and a suitable receiver can output time and frequency closely synchronized and syntonized to the CCAFS Station Clock.

The multiplexed timing signal is also transmitted, via video cable from the Station Clock, to Site Clocks which have requirements for redundant transmission paths from the Station Clock.

Each Site Clock timing signal is provided to the requiring user equipment from a separate buffered amplifier. Thus each user is unperturbed by other users collocated at the instrumentation site. Signal levels are adjustable from 0 to 10 volts (peak-to-peak or base-to-peak depending on signal type).

# DOWNRANGE STATION CLOCKS

Station Clocks at each of the downrange Stations employ redundant timing systems similar to those currently employed by the CCAFS Station Clock. However, unlike the CCAFS Station Clock which is driven directly from the Range Clock frequency standards, downrange Station Clock systems are driven from local Cesiums (only Antigua and JDMTA also employ Micro Phase Steppers). Downrange Station Clocks obtain time transfers via semi–annual portable clock calibrations from the Range Clock. Time transfers are also made using GPS, LORAN–C, Transit, GOES, and WWV timing receivers.

Replacement of the redundant downrange Station Clock equipment with the new triplicated systems is currently in progress at JDMTA and will soon be accomplished on the USNS Redstone. Modernization of the Ascension and Antigua Station Clocks is scheduled for completion before the end of 1992.

section*DOWNRANGE SITE CLOCKS Downrange Site Clocks obtain PTTI signals from the local Station Clock and provide signals to users in a manner similar to that of the CCAFS Site Clocks. The only notable difference is the absence of an UHF Radio system, however the Time Division Multiplex system is used via wideband video cables.

# SUMMARY

The ETR PTTI systems are continuously being upgraded to meet current and projected requirements. Major considerations for each of the ETR PTTI systems are accuracy, traceability, dependability, remote control automation, and low costs for implementation and operation. Generally, these systems are built using commercially available equipment, perform in various field environments, and are operated and maintained at low costs.

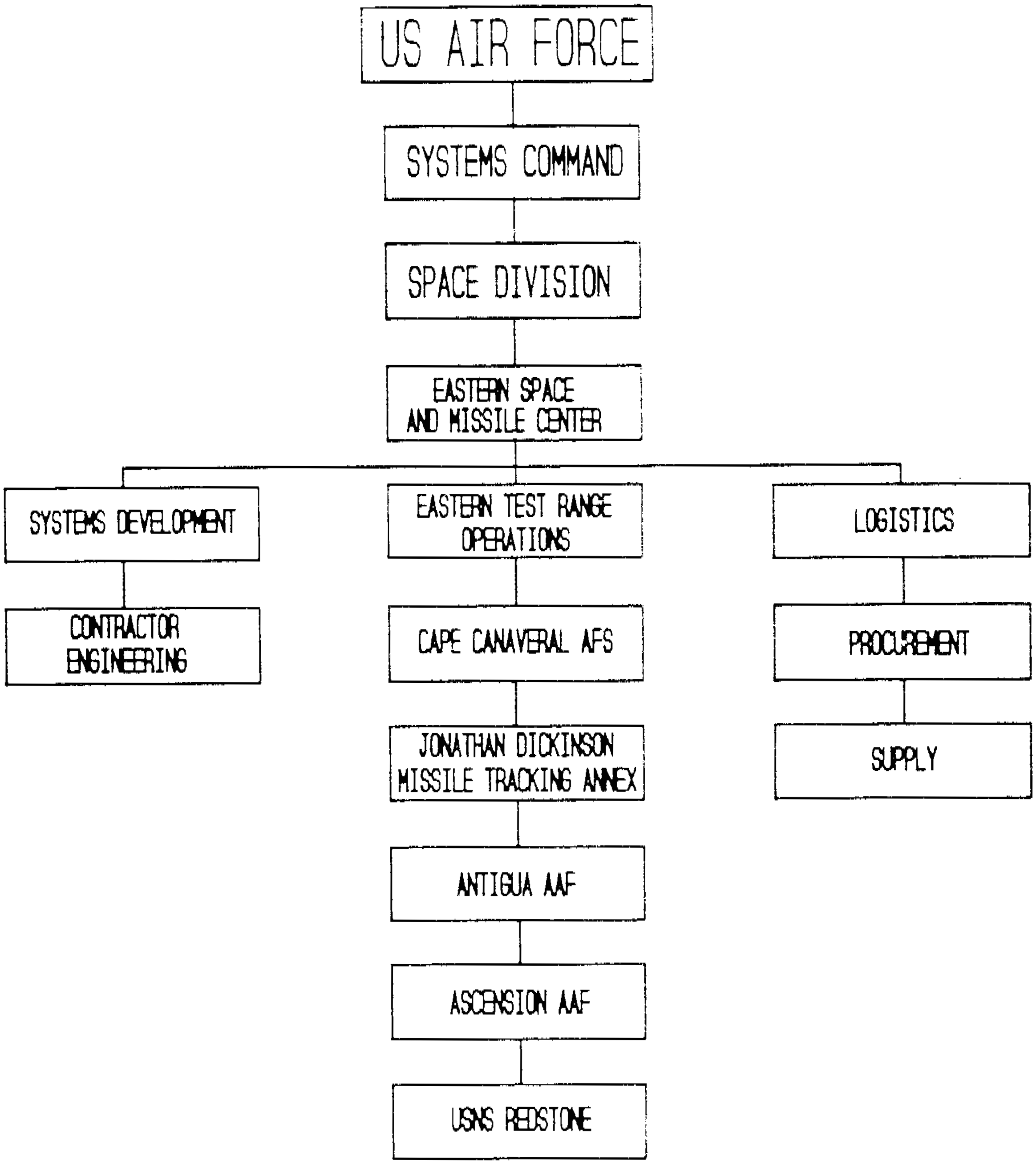


FIGURE 1 FUNCTIONAL ESMC ORGANIZATION CHART

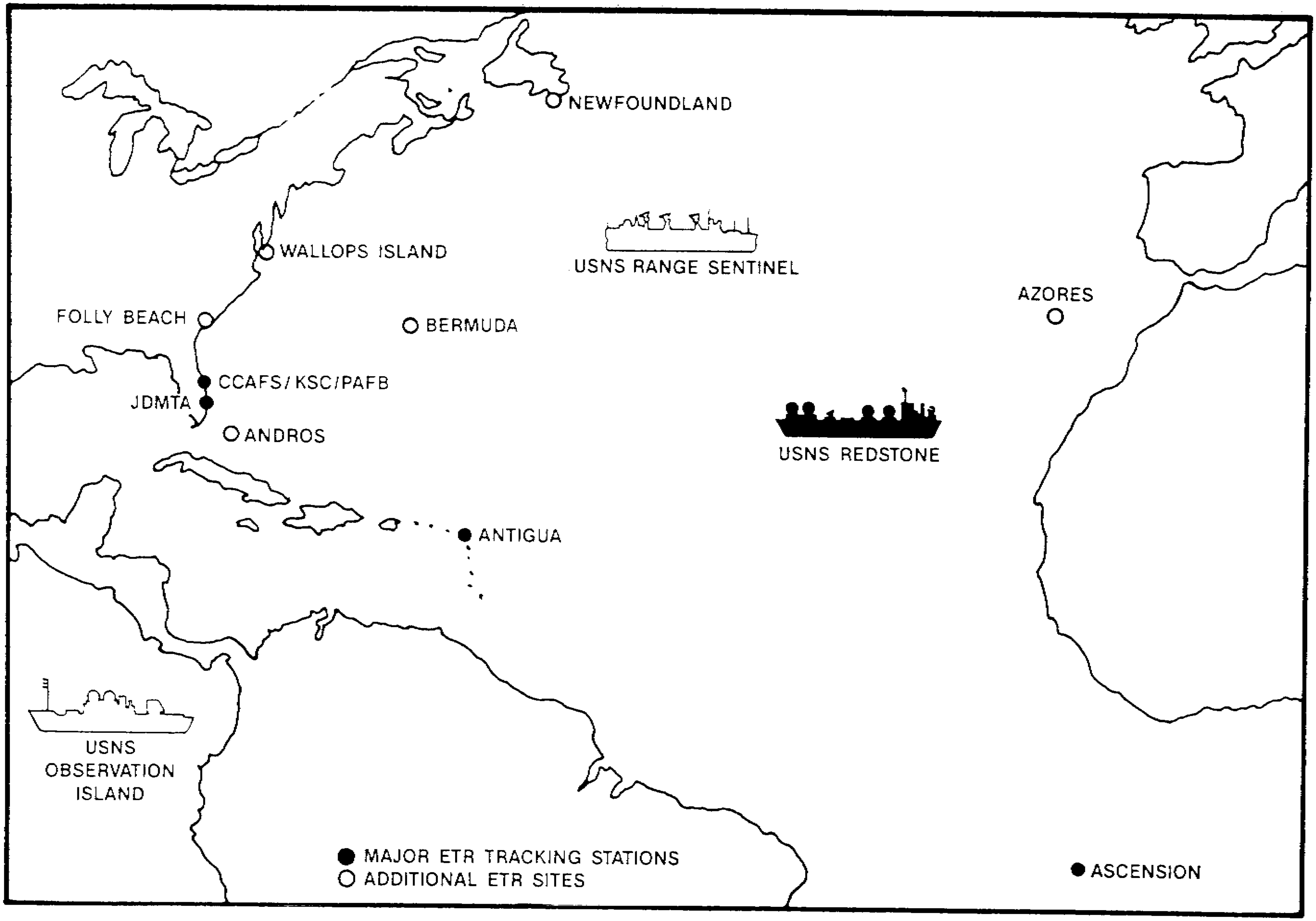
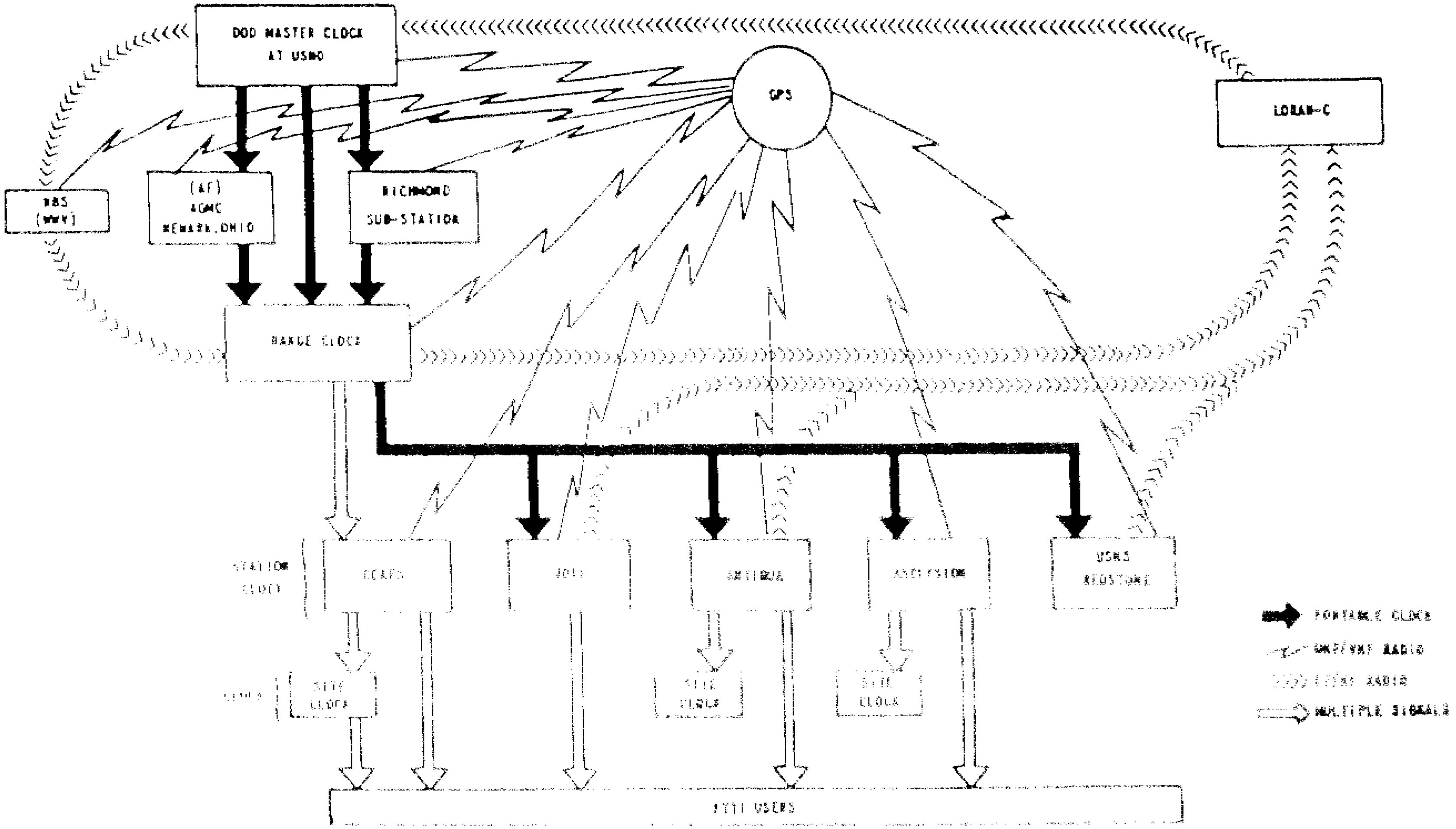


Figure 2. ETR Instrumentation Sites



ETR PTTI SYNCHRONIZATION AND TRACEABILITY

FIGURE 3

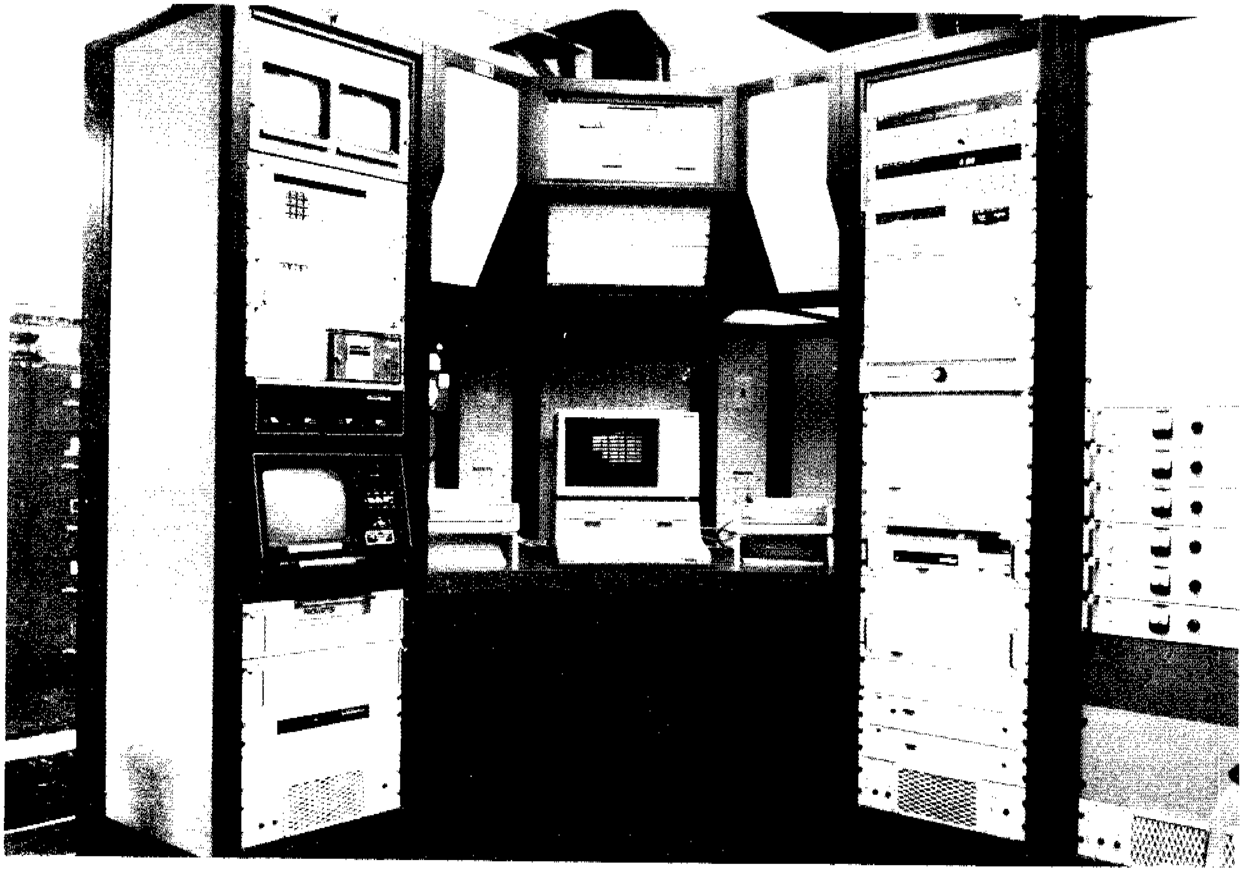
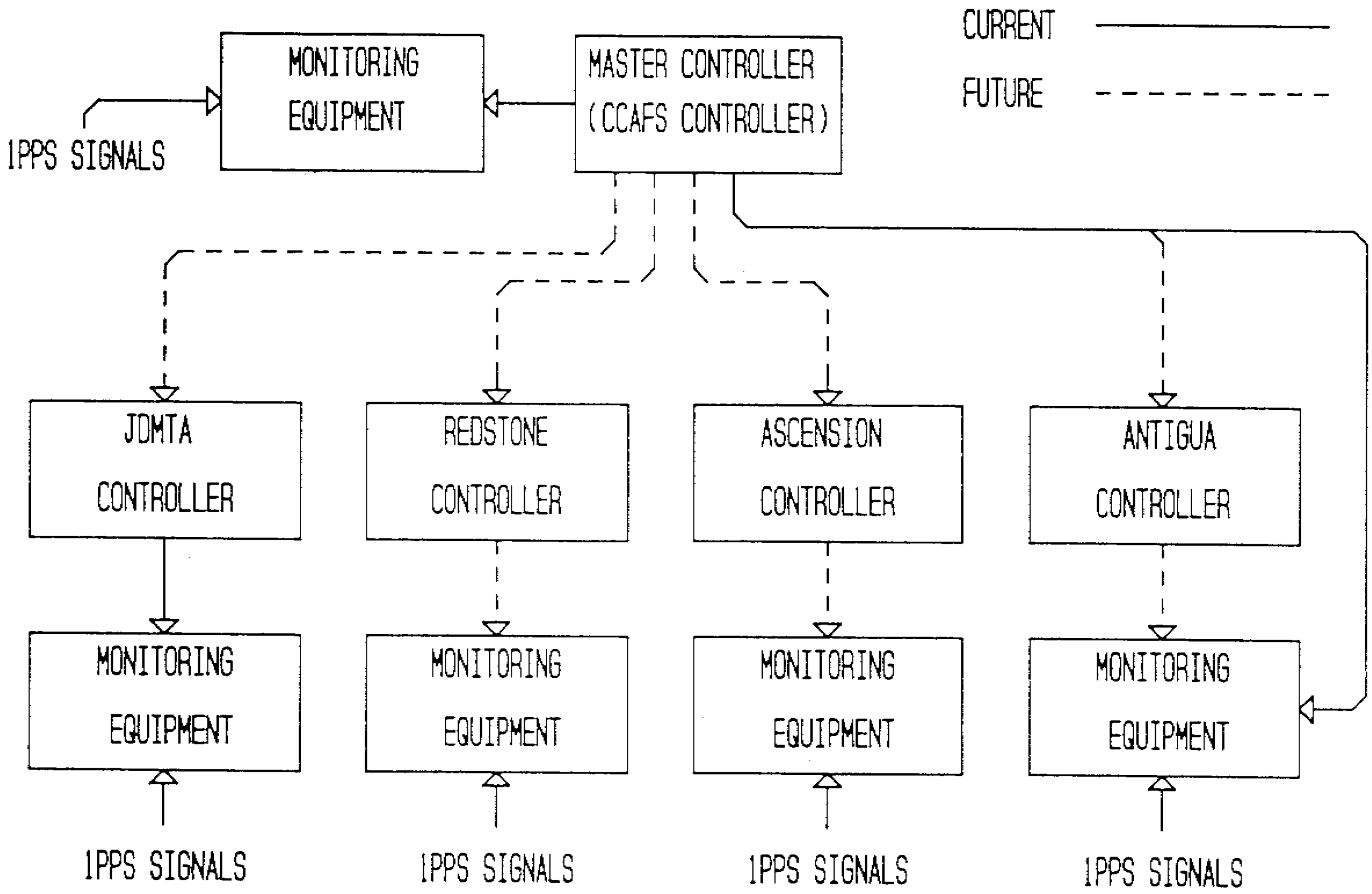


Figure 4. PTTI Monitor and Control System

Figure 5. PTTI Cesium Vault



PTTI MONITOR AND CONTROL SYSTEM

FIGURE 8