# HAWAII PTTI TEST BED

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The Navy's Precise Time and Time Interval (PTTI) program concerns many systems having to do with communications, navigation, and other time-coordinated activities. To assess the ability of the current PTTI research and development efforts to serve these systems, a test bed is being established. The Naval Communication Station at Wahiawa, Hawaii, was selected for the site because of its involvement in or proximity to a number of activities that are either dependent upon the Naval Observatory as a common reference, or could benefit from the presence of accurate time and frequency standards.

A prime goal in the effort is to develop a repertoire of techniques and equipment that will permit communications facilities to be served most effectively by their ties to a common time reference. The test bed will provide guidance for the implementation of precise time and frequency discipline at other facilities.

One product of the test-bed problem will be an assessment of the accuracy of the time-discipline chain from the Observatory to each level of use. While it is possible to estimate potential accuracies from equipment and media characteristics, the practical accuracies attainable in an operational environment must be verified or ascertained.

Current Naval Research Laboratory (NRL) test-bed development work is being done under Naval Electronic Systems Command (NAVELEX) sponsorship with financial support for equipment construction by the Naval Communications Command (COMNAVCOMM). A site survey at Wahiawa in October 1971 attended by representatives of NRL, NAVELEX, COMMAVCOMM, Naval Shore Electronics Engineering Activity (NAVSEEAPAC), and the Defense Communications Agency (DCA-PAC) was employed to establish reasonable goals and to acquire specific information about potentially affected equipment. The basic plan for the test bed was then drawn up by NAVSEEAPAC at Pearl Harbor. The plan was later modified to make best use of currently available funds, time, and talent.

The system of time standards and transfers involved in establishing a reference at Wahiawa is illustrated in Figure 1. In this sort of chain, where time transfers are not made continuously, inaccuracies may be contributed by each time-transfer process and by each secondary standard. Inaccuracies due to the transfer processes are mainly functions of equipment and transmission media, while those due to the standards depend upon rate inaccuracies of the standards and the schedules by which they are updated.

Management practices can influence the accuracy substantially. However, if the time transfers over the links from the Observatory to Brandywine and from Brandywine to

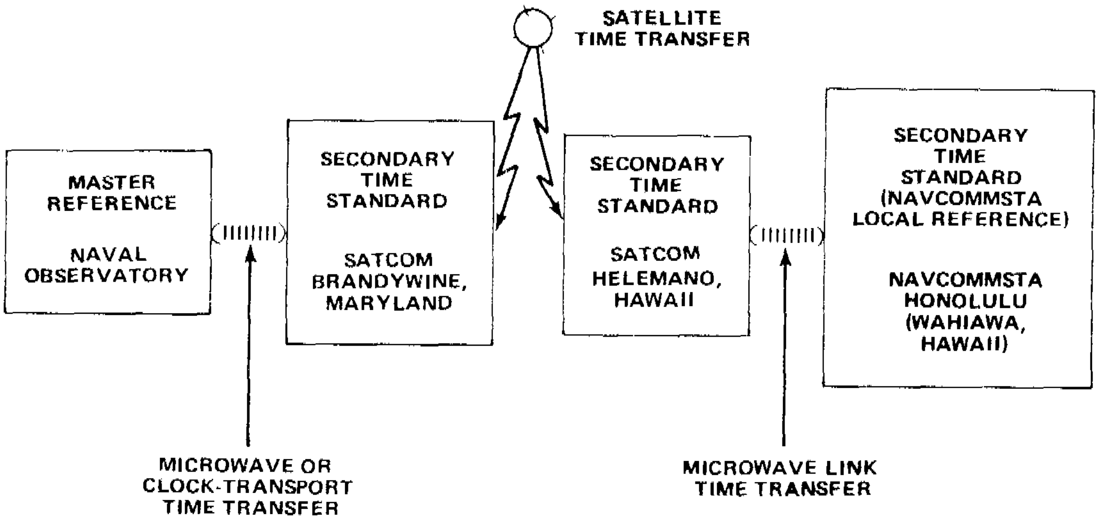


Figure 1. Timing chain from the Naval Observatory to NAVCOMMSTA Honolulu.

Helemano are made almost simultaneously, the rate error of the Brandywine standard is not important. The rate error of the Helemano standard can be similarly neglected if the time reference is passed to Wahiawa as soon as it is received from Brandywine. It would be possible then to check the Wahiawa standard against the Observatory with only the inaccuracy of three time transfers. Assuming an error of 0.1 microsecond ($\mu$s) per transfer, the standard could be checked to within 0.3 $\mu$s of the Observatory reference. Then assuming a rate error of one part in $10^{12}$ for the Wahiawa standard, a once-per-week update with 0.3 $\mu$s accuracy would keep the standard within 1 $\mu$s of the Observatory reference.

Experience with the test-bed operation should yield reasonable working values for the various accuracy factors. A figure of 1 $\mu$s for the Wahiawa standard, however, is not considered optimistic.

Most of the systems utilizing the Communication Station (COMMSTA) reference are located in the same building or nearby, and may be fed through transmission lines with fractional microseconds added inaccuracy. Any system requiring the full accuracy of the reference may be compensated for the small, fixed delay of the transmission line. Most systems require no correction.

Stabilization of the Radio Transmitting Facility (RTF) at Lualualei would employ an additional time transfer over an existing microwave link. The standards maintained at Lualualei might also be checked at reduced accuracy by monitoring the Transmitting Facility's very low frequency (VLF) broadcasts at Wahiawa. The receiving site near the Control Center at Wahiawa could be fed by coaxial line, but probably will not be implemented at this time.

The SATCOM facility at Helemano (Figure 2) not only acts as a link in the chain from the Observatory to Wahiawa, but also functions as a key terminal in distributing precise time to other satellite terminals in the western Pacific. Using a pseudorandom-noise satellite time transfer technique, many Defense Communications Agency earth terminals are being equipped for time transfer with cesium-beam clocks and time transfer equipment.

A cesium-beam clock at Helemano is its principal time standard. This clock is backed up by a disciplined time and frequency oscillator (DTFO). Under normal operation, the cesium-beam is updated periodically by time transfers from Brandywine, Md., and the DTFO is slaved to the cesium clock. The DTFO operates independently upon failure of the cesium-beam standard.

Timing signals and standard frequencies are generated by the two frequency standards and their time signal generators. An electronic counter is used for periodic checks of the time error between the two standards. The counter also serves as a readout for the time transfer unit, which is used either with the normal communications modem for time transfers with other SATCOM stations, or with a specially designed time transfer modem for clock comparisons with Wahiawa over a microwave link. Although it is not illustrated in the diagram,

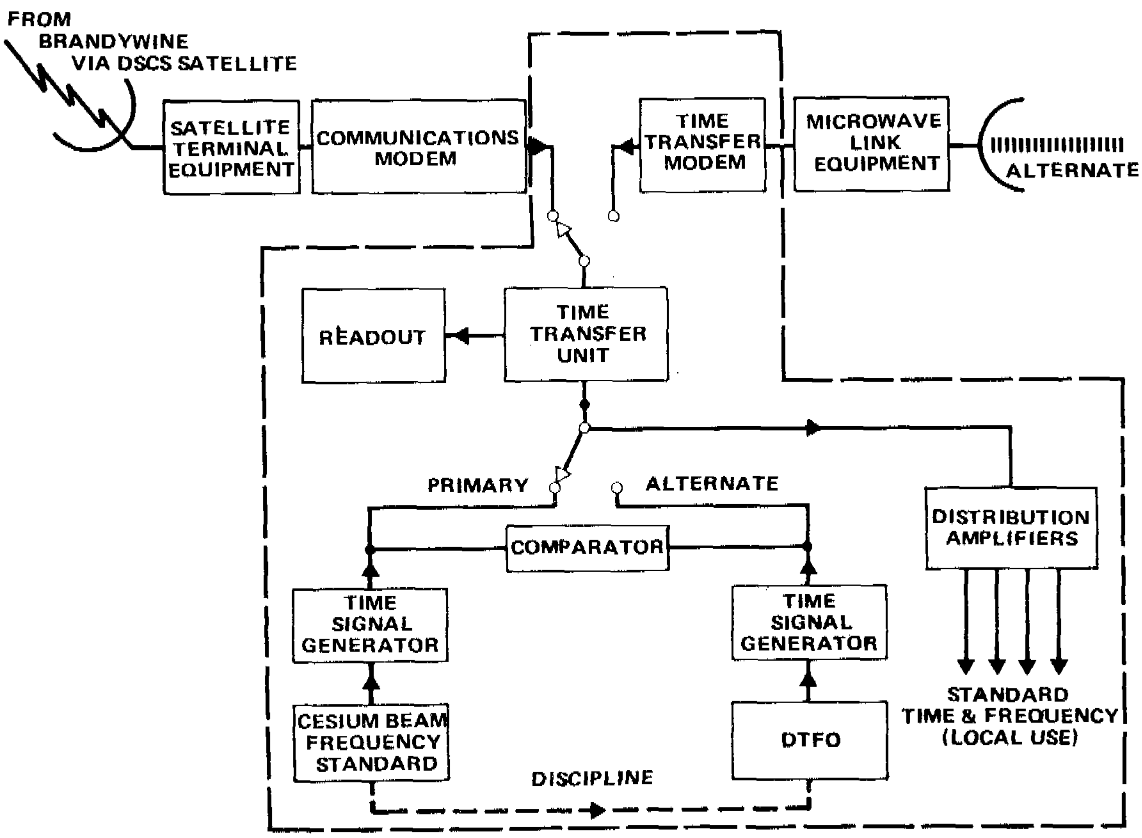


Figure 2. Helemano SATCOM time/frequency standard.

the time-transfer modem may be used with the satellite terminal to make time transfers with other satellite terminals that are not equipped with communications modems.

The time and frequency reference maintained at the communication control center at Wahiawa (Figure 3) is almost identical to the SATCOM facility standard at Helemano. The only difference is in the switching arrangements, because the Wahiawa standard does not interface with a communications modem.

Note that the Wahiawa reference may be checked at any time with the cesium-controlled references of Helemano and Lualualei. This fact gives each of the three time standards a double backup from standards of approximately equal precision.

If the cesium-beam at Helemano should fail, for example, its DTFO would then become that facility's local standard. It may be compared as often as required with Wahiawa, and indirectly with Lualualei, to maintain the required time accuracy. The Helemano DTFO may also perform the function of transfer standard between Brandywine and Wahiawa with little decrease in accuracy if it is maintained fairly well on frequency and if time transfers are passed along to Wahiawa soon after they are received from Brandywine.

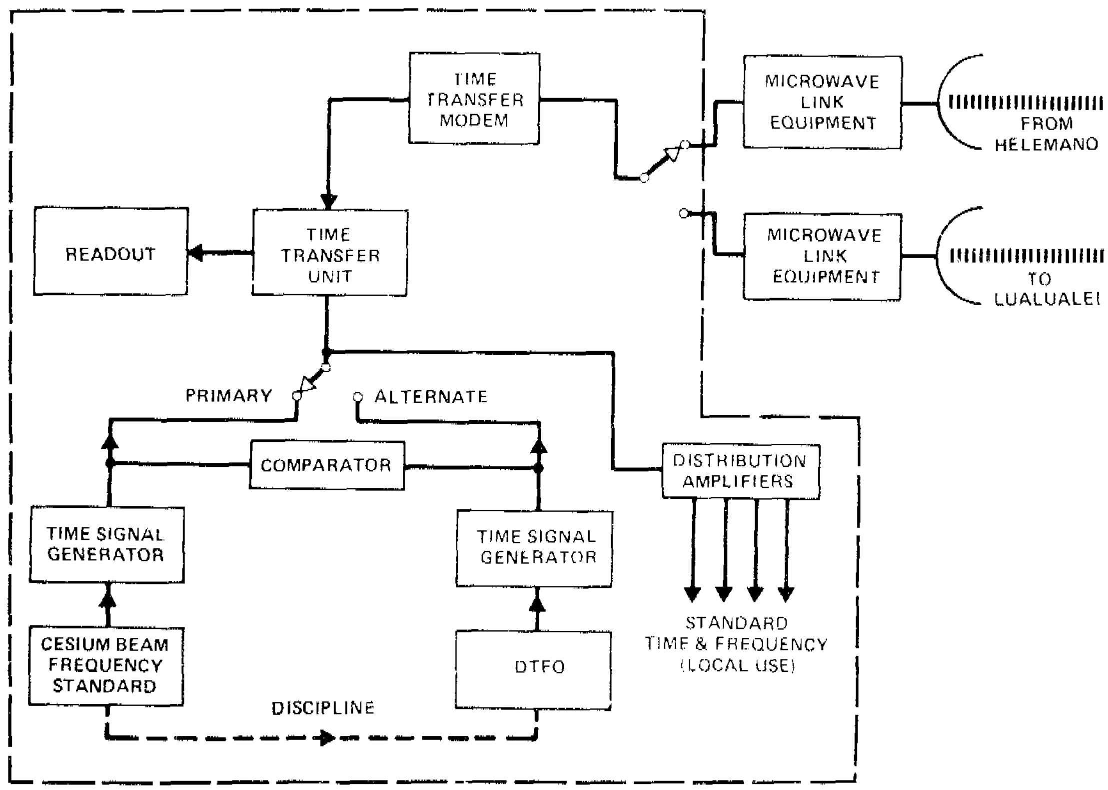


Figure 3. Wahiawa time/frequency standard.

Catastrophic failures of the major timing links may be handled in a variety of ways:

A prolonged failure of the Helemano-to-Wahiawa microwave link could be handled, for example, by transporting an accurately calibrated DTFO or cesium-beam standard from one site to the other or by simultaneously monitoring the VLF transmissions of Lualualei at the two sites.

An extended outage of the satellite link to Brandywine could be treated by reverting to indirect monitoring via the OMEGA navigation system, or the VLF transmissions of Lualualei. The link could also be replaced by occasional flying clock visits to one of the affected sites. A well established cesium-beam standard, however, may be relied upon for a frequency accuracy of nearly one part in $10^{12}$ and would gain or lose less than a microsecond per week after being set adrift. It is expected, therefore, that clock transports or indirect monitoring would be used rarely, if at all.

Examples of the methods of control and types of equipment served by the frequency standard at Wahiawa are shown in Figure 4. Sinewave signals are available from the standard at the usual frequencies of 100 kHz and at one and five MHz. Other available signals are one pulse per second, a once-per-second time code, and a one-MHz square wave that is coherent with the one pulse per second and time code.

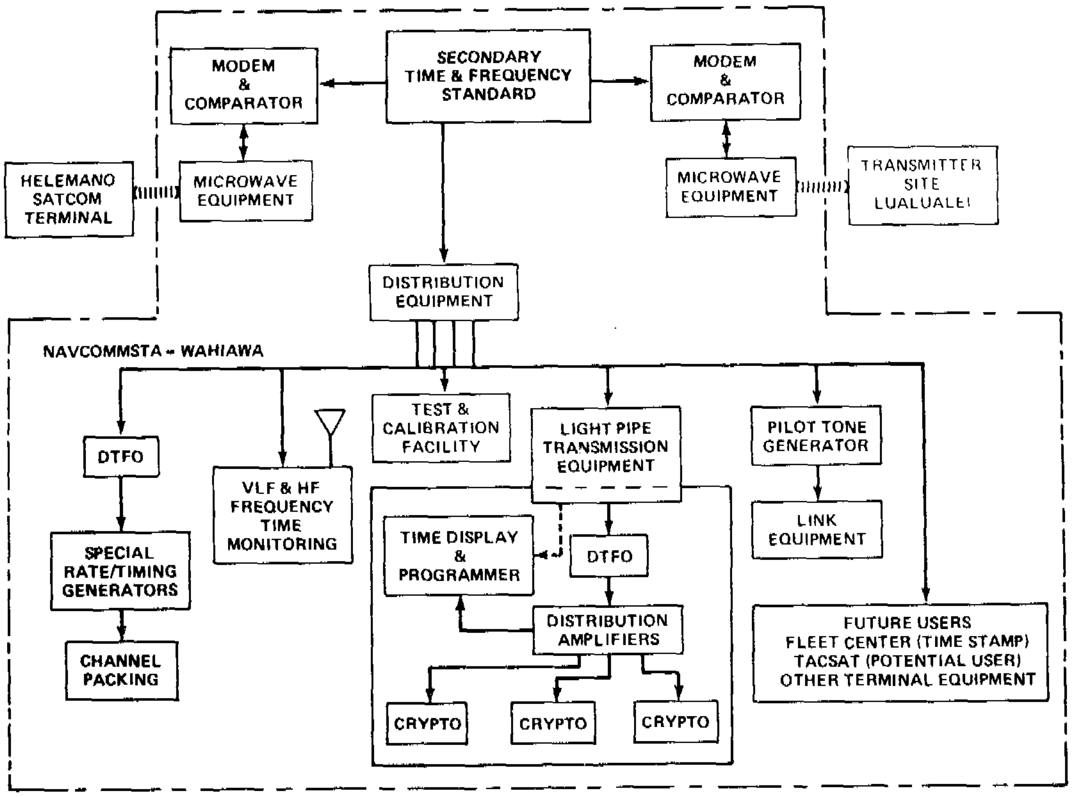


Figure 4. Precise time and frequency distribution for the Communication Control Center at Wahiawa.

It is hoped that a standard distribution format can be derived from experience with the several modes to be employed in the test bed. The time code is designed to be employed in a number of ways. A reference marker at the beginning and subsequent reference features permit equipment to be synchronized to a resolution determined largely by the bandwidth of the propagation medium between the time signal generator and the user system. The code also gives, in serial digital form, the hours, minutes, and seconds of the time of day. Data rates were selected to permit their transmission over normal voice circuits, although resolution is limited when such small bandwidths are used. Further encoding once each minute permits audible recognition of the minute and second of the hour.

A remote clock has been designed for use with the time code in varying degrees of sophistication. As a minimum function (and at minimum cost) the clock would simply read the code and display the time of day in hours and minutes; or hours, minutes, and seconds. An option will permit the clock to initiate an operation precisely at any selected second of the day. Inclusion of a controlled oscillator or use of an external 1-MHz standard frequency in another option would allow the clock to initiate an operation at precisely any microsecond of the day and to provide a fixed compensation for transmission line delay. The options employ printed-circuit cards already designed for the time signal generators at Helemano and Wahiawa.

The time display and programmer shown in the crypto area uses still another scheme to produce on-time output. The 1-Hz envelope of the time code is treated as an input frequency. The on-time leading edges of the code are counted to generate a parallel output which is decoded to drive a time-of-day display. A parallel comparator generates an output pulse when the time of day entered into a set of thumbwheel switches is reached by the counter. The time code that drives the device is also detected and updates the counter if it disagrees with the time code.

Timing signals from the Wahiawa standard will be transmitted to the crypto area through light-pipe equipment under development by the Naval Electronics Laboratory Center (NELC). DTF oscillators and automatic switching equipment will provide reliable standard frequencies to run the equipment, while the time display and programmer will provide precise timing events for equipment synchronization.

The channel packing program will be served by special timing generators to maintain accurate rates. Two DTF oscillators will provide a reliable reference to control the rates and will maintain alignment with respect to a one-pulse-per-second signal.

Although it is not scheduled for the present test bed installation, provisions can easily be made to monitor the frequency and timing of VLF and high-frequency (HF) broadcasts from the radio transmitting facility at Lualualei. When timing is eventually added to the keystream of the VLF transmissions, it may be effectively monitored and disciplined by Wahiawa, which is relatively free of unbalanced pickup from the two towers of Lualualei.

Frequency dividers will be provided for the test and calibration facility at Wahiawa. Test signals of 1 MHz and 1 kHz will be supplied.

A pilot tone-generator will provide an accurate 96 kHz frequency to discipline a microwave link network.

The availability of an accurate time and frequency reference at the communication station will permit equipment and systems to be simplified by relieving them from independently having to establish and maintain time and frequency accuracy. Among the potential beneficiaries are the Fleet Center, which could use precise message dating equipment and time-of-day displays, and the TACSAT communications system.

The receiver site illustrated in Figure 5 is not currently scheduled to be a part of the test bed, but could benefit by standard-frequency distribution to drive the frequency synthesizers of its receivers. In this application, spectral purity is important, because a noisy input may produce a noisy output.

The DTF oscillators at the receiving site make the site independent of the control-center standard during any distribution system failure. They also provide spectrally clean signals to the receivers, even if the line between the control center building and the receiving site picks up some noise.

Accuracy is degraded gradually after the DTFO loses its reference. During a distribution system outage, an unattended DTF oscillator would maintain a frequency accuracy better

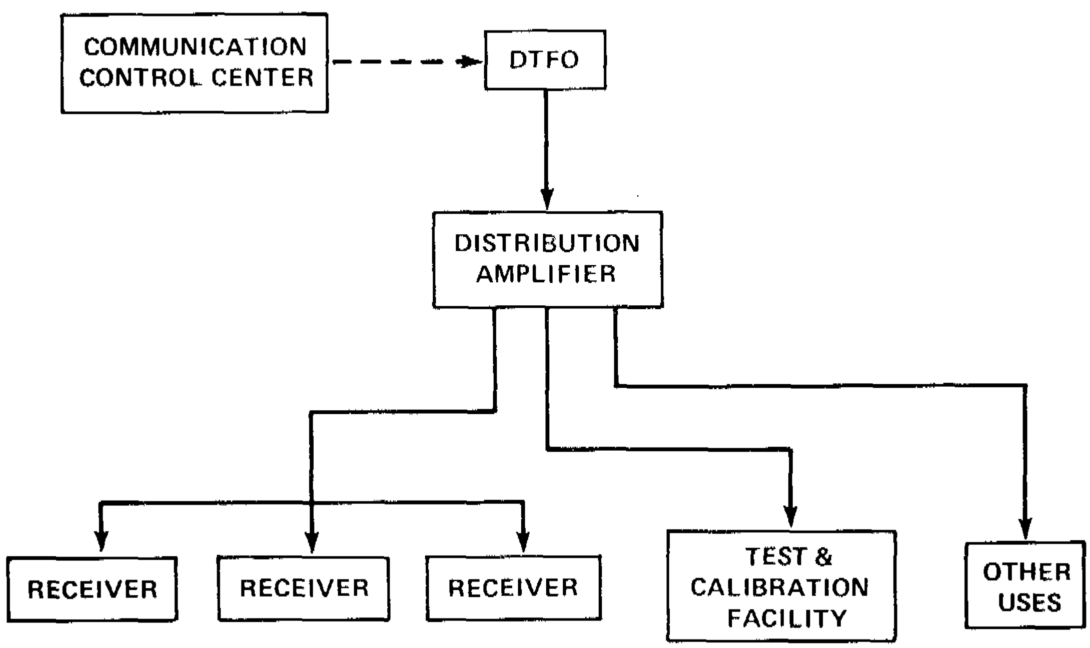


Figure 5. Precise time and frequency distribution for the receiver site at Wahiawa.

than one part in $10^9$ for 20 days. This exceeds the requirements of the receivers by a sizable margin. One practical advantage of a distribution system of this type is the elimination of maintenance otherwise required to calibrate numerous individual frequency standards. As in the control center, standard frequency test tones and signals may be easily provided for frequency counters, signal generators and other frequency-dependent instruments.

The transmitter site (Figure 6) may be brought under the guidance of the NAVCOMMSTA time and frequency reference at Wahiawa through time transfers over an existing microwave link between the two sites. Only one additional time transfer modem would be needed, because Wahiawa will already possess such a unit for time transfers with Helemano.

One of the two cesium-beam frequency standards that now control the VLF transmitter would be moved to the Lualualei microwave terminal and serve as the transmitting facility reference. Each transmitter building or building wing would contain a DTFO that is disciplined by the reference. Transmitter spectral purity and accuracy requirements are similar to those of the receivers.

Because of the large distances between buildings (a mile or more in some cases), and the very strong high-frequency electromagnetic fields present throughout the site, distribution

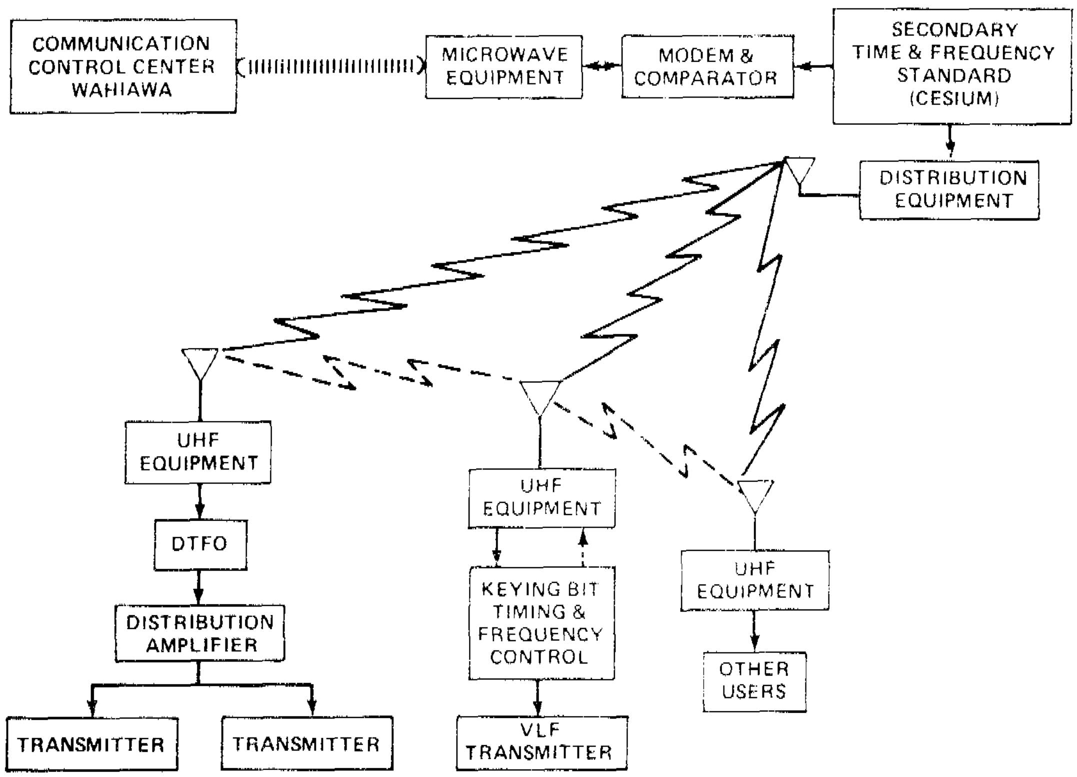


Figure 6. Precise time and frequency distribution for the transmitter site at Lualualei.

by coaxial cable could be both expensive and noisy. Current plans are to distribute the reference via low-power ultra-high-frequency (UHF) signals broadcast from the site of the reference. A UHF transmitter at the VLF site, the location of the other cesium-beam standard, could take over during any extended outage of the transmitter facility reference.

A format for the UHF broadcasts has not yet been chosen. A standard-frequency signal, amplitude- or frequency-modulating the UHF carrier would serve all of the transmitters except for the VLF and could be filtered effectively because of its narrow-band nature. However, the VLF transmissions must be controlled in time, and a time code is preferred.

Distribution of standard frequencies within the transmitter buildings by light pipes to avoid ground-loop problems in those high-field areas has been considered.

One of the first considerations in the implementation of any distribution system must be the consequences of its failure. A failure that would cause only a momentary malfunction of one user system might be catastrophic to another. The momentary loss of a standard frequency to a radio receiver, for example, might cause it to miss a few bits of data or a word of speech. The same momentary loss to a timing system could render it inaccurate forever afterwards. There are users subject to all degrees of inconvenience between these extremes.

The crypto-equipment at Wahiawa is a group of systems for which continuity of standard-frequency input is important. A passive auto-switch shown in Figure 7 has been designed to provide that continuity by selecting an available signal from one of two input lines. The switch is passive in that it operates completely from power supplied by the input signals.

One signal supplies the output and suppresses the other signal channel. If the first signal fails, the second channel becomes active and suppresses the first. The switch can be manually set to either channel, provided that it has an input of sufficient amplitude. Loss through the active channel is approximately three decibels (dB) at one volt root-mean-square (rms), and the inactive channel is suppressed approximately 25 to 30 dB. A slight discontinuity occurs at the instant of switching, but should not amount to more than a few microseconds.

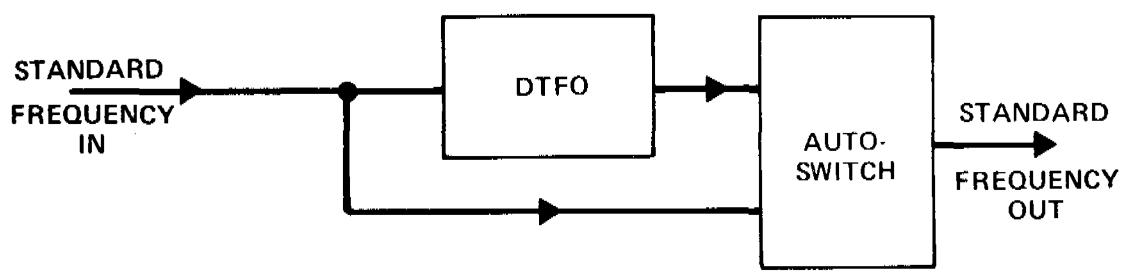


Figure 7. Passive autoswitch for timing applications.

The diagram illustrates one possible use of the switch. Under normal circumstances, the standard frequency input is routed through the switch. But if it fails, the DTFO output is channeled through instead.

The test bed effort has required the development of a number of new equipments, which are now in various stages of completion. The baud rate generator illustrated in Figure 8 produces basic frequencies to discipline a microwave system, the channel-packing modem, and a digital communications system. The microwave pilot tone and the basic channel-packing frequencies are maintained in alignment with a 1PPS input. One or more baud rate divider amplifiers driven by the generator produce square waves of 75 Hz X $2^n$ up through 9.6 kHz with positive-going edges on time with 1PPS.

The status of the generating system, which includes a servo-controlled crystal oscillator is displayed on the front panel. Normally, the reference for the check is 1PPS, but the 9.6 kHz reference may be selected for a rarely required maintenance procedure.

Battery backup is accommodated in this unit as in all other critical equipments for the test bed by provision of a connector for an external battery and appropriate automatic-internal switch-over circuitry. Nominal battery voltage is 24 volts, while some units can also accept 12 volts. Normal operation is at 115 volts 50-400 Hz.

The crypto-equipment is driven by a specially shaped 100-kHz square wave that is produced by amplifiers of the type shown in Figure 9. Each amplifier has 12 outputs; each of which can drive one or two machines. This unit can accept battery backup at 12 or 24 volts.

Distribution of the time code, 1PPS, and the timed one MHz is provided by the line driver of Figure 10. The unit contains four independent amplifier cards, each containing three output amplifiers. The inputs and outputs of individual cards may be made balanced or unbalanced, by switch selection. And high impedance or 50-ohm inputs may also be selected.

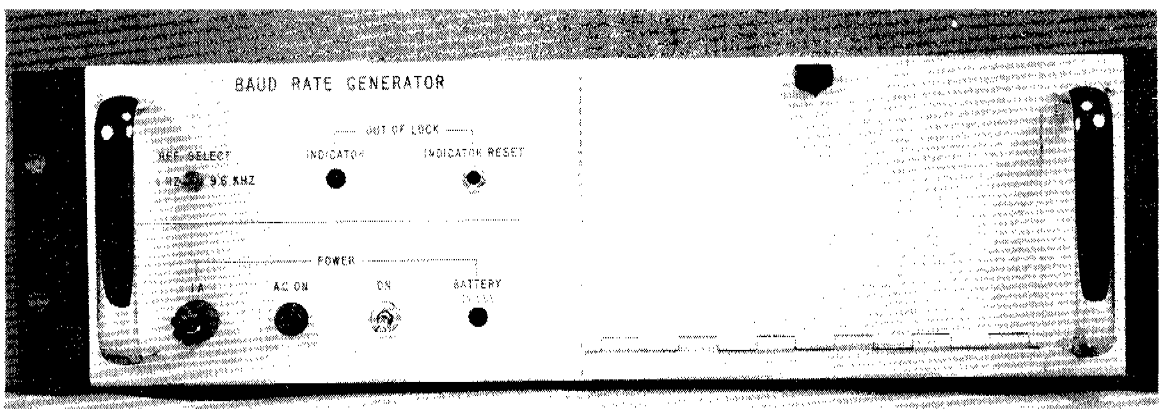


Figure 8. Baud rate generator.

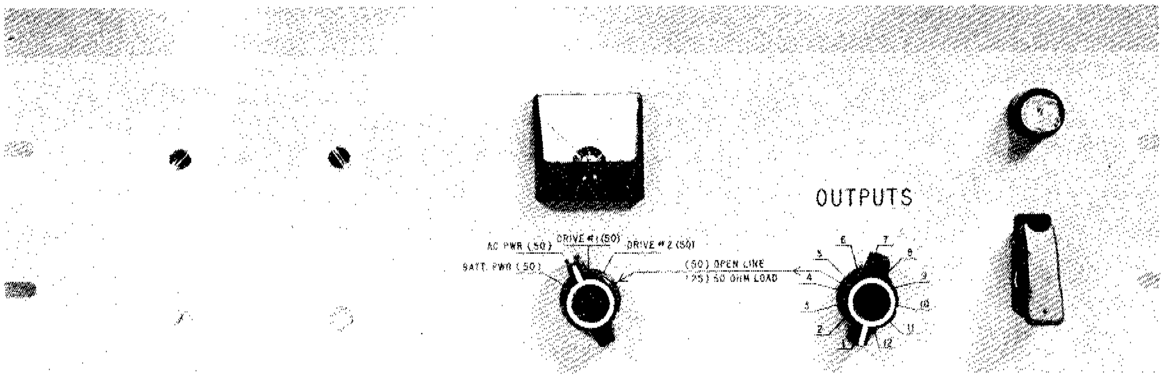


Figure 9. Distribution amplifier for crypto equipment.

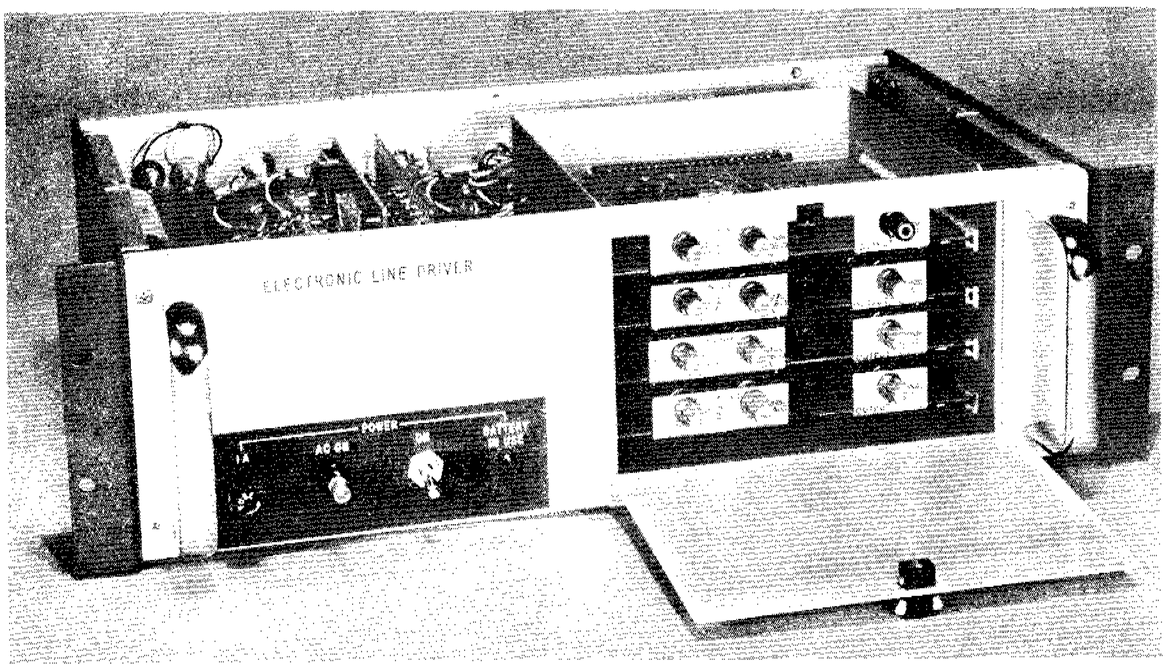


Figure 10. Timing signal distribution amplifier.

Time transfers between Helemano and Wahiawa will be made with the time transfer modem (Figure 11). This unit employs a pseudo-random noise code as a vehicle for effectively sending very short pulses from one site to another.

The modem is capable of operation over satellite links as well as fixed microwave links. Input and output are at a nominal 70 MHz, but a baseband interface is also provided for operation with certain link equipment. Bit rates from 1.25 MHz to 10 MHz may be selected to match bandwidth availability.

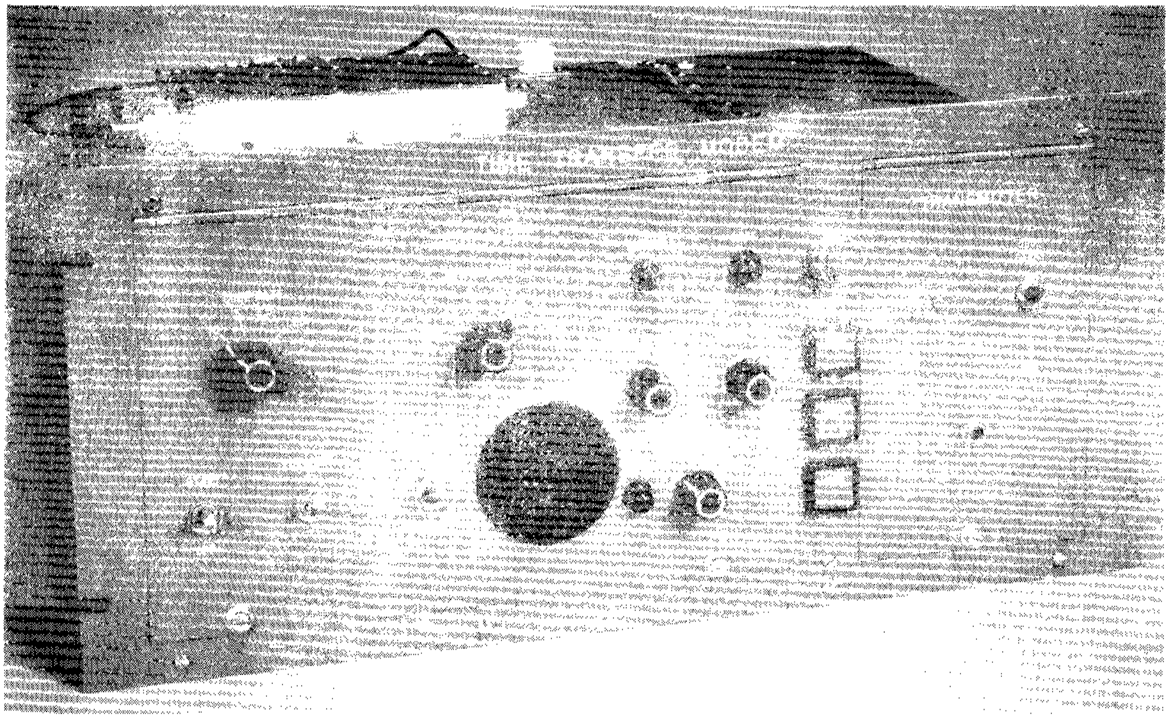

Figure 11. Time transfer modem.

Since the modem may be operated at a large bandwidth and below the level of interfering signals, the modem may be used in a lightly populated channel without significant mutual interference. This mode of operation has been used on the satellite links. For the line-of-sight microwave circuits in Hawaii, however, the channels are heavily occupied; and the modem spectrum will be reduced in width and converted to a lightly occupied region of the channel.

The time-transfer modems are used with time-transfer units in a two-way process that effectively cancels out the propagation time, and therefore gives direct clock comparisons without requiring a distance correction. Accuracy is in the order of 0.1$\mu$s for all bit rates and is limited primarily by the readout resolution of the counter at the higher bit rates.

The remaining units designed for the test bed, including the time signal generator, the time display and programmer, the test-signal interface, the auto switch, and selector switch panels are currently under construction and should be completed in about a month.