ON THE FREQUENCY AND TIME STANDARD IN THE TELECOMMUNICATION LABORATORIES, MINISTRY OF COMMUNICATIONS

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OUTLINE

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ABSTRACT

The present status of the Standard Frequency & Time system in Telecommunication Laboratories of the Republic of China is presented. The heart of this system is an ensemble of four cesium beam frequency standards. Incorporated with this ensemble are various equipments such as counters, linear phase detectors, VLF receivers and LORAN-C receivers. The method currently used for determining time from this ensemble will be outlined.

The receiving of LORAN-C signal from the master station of the Northwest Pacific LORAN-C Chain provides time linkage between Telecommunication Laboratories and Bureau International de l'Heure (B.I.H.). The difference between the coordinated universal time (UTC) kept by Telecommunication Laboratories and that of B.I.H. for the last ten years are presented. Based on these data, the dependence of frequency stability on the sampling time intervals has been analyzed, starting from sampling time intervals of 10 days with a step increase of 10 days up to 100 days. The results show that the frequency stabilities are 6.783×10^{-13} and 1.76×10^{-12} for sampling time intervals of 10 days and 100 days, respectively. The frequency statility increases with increase of sampling time interval. The average frequency stability determined for the sampling time interval of 10 days up to 100 days is found to be 1.270×10^{-12}.

For public services, the Tecommunication Laboratories established a standard time and frequency broadcasting station (call sign BSF) in 1969. A brief introduction to this station will be made.

1. INTRODUCTION

Measurements in time and frequency are of fundamental importance in all experimental works of science and engineering. This can be easily seen from the fact that time is an important parameter in equations that describe natural phenomenon. Time has two distinct aspects : epoch and time interval. Epoch is concerned with when an event occured; time interval is concerned with the unit of time and is independent of a starting point. Both the determination of time interval and the determination of epoch are important to time-keeping. These determinations involve the search of generation of a time scale which is uniform, accurate and reliable. The generation of universal coordinated time of the Telecommunication Laboratories, UTC(TL), is based on these requirements.

Time interval is one of the base units of the International System of Units of Measurements (S.I.). The S.I. unit of time interval is the "SECOND". Frequency, which is dimensionally the reciprocal of time interval, is a derived unit in the S.I. system. The present definition of the "SECOND" states : "The SECOND is the duration of 9,192,631,770 periods of the radiation corresponding to transition between the two hyperfine levels of the ground state of the cesium-133 atom." Today, two time scales are available worldwide : The International Atomic Time (TAI) and the Universal Coordinated Time (UTC). TAI is the reference coordinate of time established by the Bureau International de l'Heure (BIH) on the basis of the readings of atomic clocks functioning in various establishments around the world. UTC, also established by BIH, is derived from TAI. It is using information on Universal Time contributed by astronomical observatories of world wide distribution. UTC and TAI have the same interval but differ in epoch.

Frequency source coupled with suitable frequency divider and display units forms a "clock". The precision frequency sources are cesium beam resonator, hydrogen maser, rubidium vapor cell and quartz oscillator. At present, cesium beam resonater (or cesium beam frequency standard) has an almost unique position in the field of standard frequency and time for its intrinsic accuracy, reproducibility, long-term stability and commercial availability. Most laboratories which are taking part in the formation of UTC and TAI of BIH use cesium beam resonators as their frequency sources[1]. Telecommunication Laboratories makes no exception. A simplified block diagram of cesium beam resonator is shown in Fig.1. Basically, it is a quartz oscillator stabilized with a cesium resonator.

It is that time and frequency can be transmitted by radio waves that make them unique among the physical quantites. There are many dissemination techniques for time and frequency transfer.

Among them,. the LONG RANGE NAVIGATION SYSTEMS (LORAN-C), which are operated by the United States Coast Guard, provide time linkages among the various laboratories of the northern hemisphere.

Frequency stability parameters are important in specifying a frequency standard. Frequency stanility can be measured in the frequency domain or in the time domain. For precision oscillators, these two measurements are closely related.

2. THE STANDARD FREQUENCY and TIME SYSTEM of the TELECOMMUNICATIONN LABORATORIES

The Radio Science Laboratory of The Telecommunication Laboratories maintains an ensemble of four commercial cesium beam frequency standards, which provide a realization of the time scale, UTC(TL). We also monitor LORAN-C, VLF and HF signals to provide time linkage. The data are all refered to UTC(TL). Direct Frequency measurments are also conducted to provide frequency calibration. To provide non-profit service to the public, Telecommunication Laboratories also operates Standard Frequency and Time Broadcas Station, call sign BSF.

2.1 STANDARD FREQUENCY AND TIME GENERATION

The block diagram of standard frequency and time generation of the Telecommunication Laboratories is shown in Fig.2. It consists of four HP 5061A Cesium Frequency Standards with digital clock option. UTC(TL) is kept with master clock driven by one of the cesium standard via a microphase stepper. DC battery back-up enhances reliability. More than three cesium frequency standards are used to provide redundancy. Mutual clock comparisons among cesiums standards are made per day with precision 0.01us. Phase comparison among cesium frequency standard are also recorded continuously on 1 MHz.

If ideal clock were ever available, then the time of the clock will move away in a linear manner from an ideal time scale as shown in Fig.3(a). Any physically realizable clock will always have time errors as shown in Fig.3 (b). There are two kinds of time errors : determininstic and random. The most common time errors are : synchronization error, frequency drift changes, frequency offset, steps in frequency, steps in time and random noise. In mathematic form :

$$Ti(t) = Ti(to) + Ri(to)(t-to) + (1/2)Di(to)(t-to)^2 + X(t) \qquad (1)$$

where:

- Ti(t) : clock i reads at time t
- Ti(to): synchronization errors at t=to
- Ri(to): rate of change, equals to fractional frequency change.
- Di(to): linear frequency drift. $\Delta f/f$ per month.

(negligible in Cs. frequency standard)
X(t) : random time errors

The intercomparisions of phase and time among cesium frequency standards are for detection of the deterministic time error. The UTC(TL) generation flow chart is shown in Fig.4.

2.2 UTC(TL) AGAINST UTC(BIH) VIA LORAN-C RECEPTION

LORAN-C is a long-range pulsed-hyperbolic radio navigation system operating at 100 KHz carrier frequency. A LORAN-C Chain consists of a master and two or more slave stations. Adjacent chains employ different repetition rates for identification. The pulse length is approximately 300us. LORAN-C stations transmit a burst of eight pulses spaced 1 ms apart during each repetion period. The master station transmits a ninth pulse, 2 ms after the eighth for identification. Fig.5 is a representation of the Northwest Pacific LORAN-C Chain. Most East Asian countries use this LORAN-C Chain for time linkage. Transmission of LORAN-C master stations are steered by the United States Naval Observatory to be synchronous with the UTC(USNO), with reference to an epoch. The reference epoch has been established as 0000 hours UT, January 1, 1958, at which time it is assumed that the first pulse of the master station of each LORAN-C Chain so synchronized was transmitted. Times of coincidence (TOC) between this pulse and the UTC(USNO) will occur periodically, at which times clocks can be set to the LORAN-C transmission. The number of seconds for coincidence, T and LORAN-C Chain repetition rate are related by :

$$T = \frac{\text{Repetition Period}}{1,000,000} N \qquad (2)$$

Where N and T are integers.

For the Northwest Pacific LORAN-C Chain, the number of seconds for coincidence is 997 seconds. The most difficult problem of using LORAN-C for timing is the estimations of propagation delay and receiver delay.

Usually the receiver delay is supplied by the LORAN-C manufacturer. The transmission delay can be estimated from calculations of the Great Circle distance and estimation of transmission modes. If microsecond or higher accuracies are required then it must be determined by protable clock trip. The transmission delay between TL and the Master Station, Iwo Jima, has been measured by portable clock visit from United States Naval Observatory. It is 6795.0 us. UTC(TL) can be related to UTC(BIH) via this

LORAN-C signal reception. Fig.6 shows the time differences between UTC(TL) and UTC(BIH) for the last ten years.

3. FREQUENCY STABILITY ANALYSIS OF UTC(BIH) VERSUS UTC(TL)

3.1 BASICS OF FREQUENCY STABILITY MEASURE

Frequency stability is the degree to which an oscillating signal produces the same value of frequency. It is most importatant to most frequency and time metrologist. Stability can be characterized in the frequency domain or in the time domain. The instantaneous fractional frequency deviation y(t) from the nominal frequency fo is related to the instantaneous phase deviation $\phi(t)$ by

$$y(t) = \dot{\phi}(t) / 2\pi f_o \tag{3}$$

In the frequency domain, frequency stability is defined as Sy(f), the one-sided spectral density of y(t). It is related to the $S_\phi(f)$, the one-sided spectral density of phase by

$$S_y(f) = \frac{f^2}{f_o^2} S_\phi(f) \tag{4}$$

In the time domain, frequency stability is defined by the sample variance :

$$\sigma_y^2(N,T,\tau,f_h) = \left\langle \frac{1}{N-1} \sum_{n=1}^{N} \left(\bar{y}_n - \frac{1}{N} \sum_{K=1}^{N} \bar{y}_K \right)^2 \right\rangle \tag{5}$$

where < > denotes an infinite time average. N is the frequency readings in measurements of duration τ, T is the time interval between measurements and fh is the measurements bandwidth. For some noise processes, $\sigma y^2(N,T,\tau,fh)$ will not convergient so as to obtain a meaning value. In the field of frequency standards, frequency stability has become almost universally understood as meaning the square root of the two sample variance of N=2 and $T=\tau$ in equation (5). It is commonly called the Allan Variance, $\sigma_y^2(\tau)$.

$$\sigma_y^2(\tau) = \left\langle \frac{(\bar{y}_{K+1} - \bar{y}_K)^2}{2} \right\rangle \tag{6}$$

For M times of frequency readings, equation (6) can be approximated by

$$\sigma_y^2(\tau) \approx \frac{1}{2(M-1)} \sum_{K=1}^{M-1} (\bar{y}_{K+1} - \bar{y}_K)^2 \quad (7)$$

$\bar{y}_{K+1}$ can be related to clock readings by

$$\bar{y}_{K+1} = \frac{1}{\tau} (x_{K+1} - x_K) \quad (8)$$

where :

x_K : clock reading at $t=t_K$
x_{K+1}: clock reading at $t=t_K+\tau$

A spectral model that has been found very useful represents the Sy(f) as [3] :

$$S_y(f) = h_{-2}f^{-2} + h_{-1}f^{-1} + h_0 f^0 + h_1 f^1 + h_2 f^2 \quad (9)$$

for $f_l < f < f_h$
where :

$h_{-2}f^{-2}$: random walk frequency noise.
$h_{-1}f^{-1}$: flicker froquency noise.
$h_0 f^0$: white frequency noise.
$h_1 f^1$: flicker phase noise.
$h_2 f^2$: white phase noise.

The Sy(f) is zero outside of this frequency range, $f_h - f_l$. The lower cutoff frequency f_l may be selected as a frequency below the fundamental frequency of the longest observation period. The Sy(f) or $S_\phi(f)$ plot of a typical oscillator's output usually is a combination of different power law noises. For power-law noise processes, the conversions between frequency and time domain can be found in barnes, et. al.[3].

3.2 STABILITY ANALYSIS of UTC(TL) VERSUS UTC(B.I.H.)

An stability analysis of the time difference data of UTC(B.I.H.) versus UTC(TL) for the past four years has been made based on equations (7) and (8). The sampling time interval has been incresed from 10 days to 100 days with a step increase of 10 days. The results are shown in Fig.7. The froquency stabilities are found to increase slightly with increase of sampling time interval. From the conversion, we know that the flicker frequency noise will result in a constant Allan variance and the random walk frequency noise, an Allan variance that is proportional to sampling time interval. We conclude that the noise were around the corner where the flicker frequency noise process and random walk frequency noise process met and that the fliker frequency noise were more predominant. The average value of $\sigma_y(\tau)$ is found to be 1.270×10^{-12}. Applying flicker frequency noise process, then the one-sided spectral density of y is found to be $1.61 \times 10^{-24}/f$ per Hz for Fourier frequency $f<10^{-6}$ Hz.

4. THE STANDARD FREQUENCY and TIME BROADCAST STATION "BSF"

The Station "BSF" is located at the outskirts of the Telecommunication Laboratories and broadcasts daily at 5 MHz and 15 MHz.

The frequency sources used in the "BSF" station are two rubidium vapor frequency standard. The signals from frequency source have been processed through frequency division, frequency multiplication, control and amplification. We adopt lengthing seconds method to disseminate the information of DUT1, which is the time differce between time scale UT1 and time scale UTC.

5. CONCLUSION

We have presented the present status of the standard frequency and time system in the Telecommunication Laboratories of the Republic of China. UTC(TL) time generation, frequency stability measure and analysis of UTC(TL) Vs UTC(BIH) have also presented. From the above discussion. We have the following observations :

1) The basic requirements of time scale generation are uniform and accurate. How to determine time errors is a prerequisite for uniform and accurate time generation.
2) The factors affect the stability measure of UTC(TL) versus UTC(BIH) may come part from the abnormality of the LORAN-C signal transmission. Correct prediction of this factor will result in a smaller $\sigma_y(\tau)$.
3) Frequency stability measure is important in specifying oscillators.

6. ACKNOWLEDGMENTS

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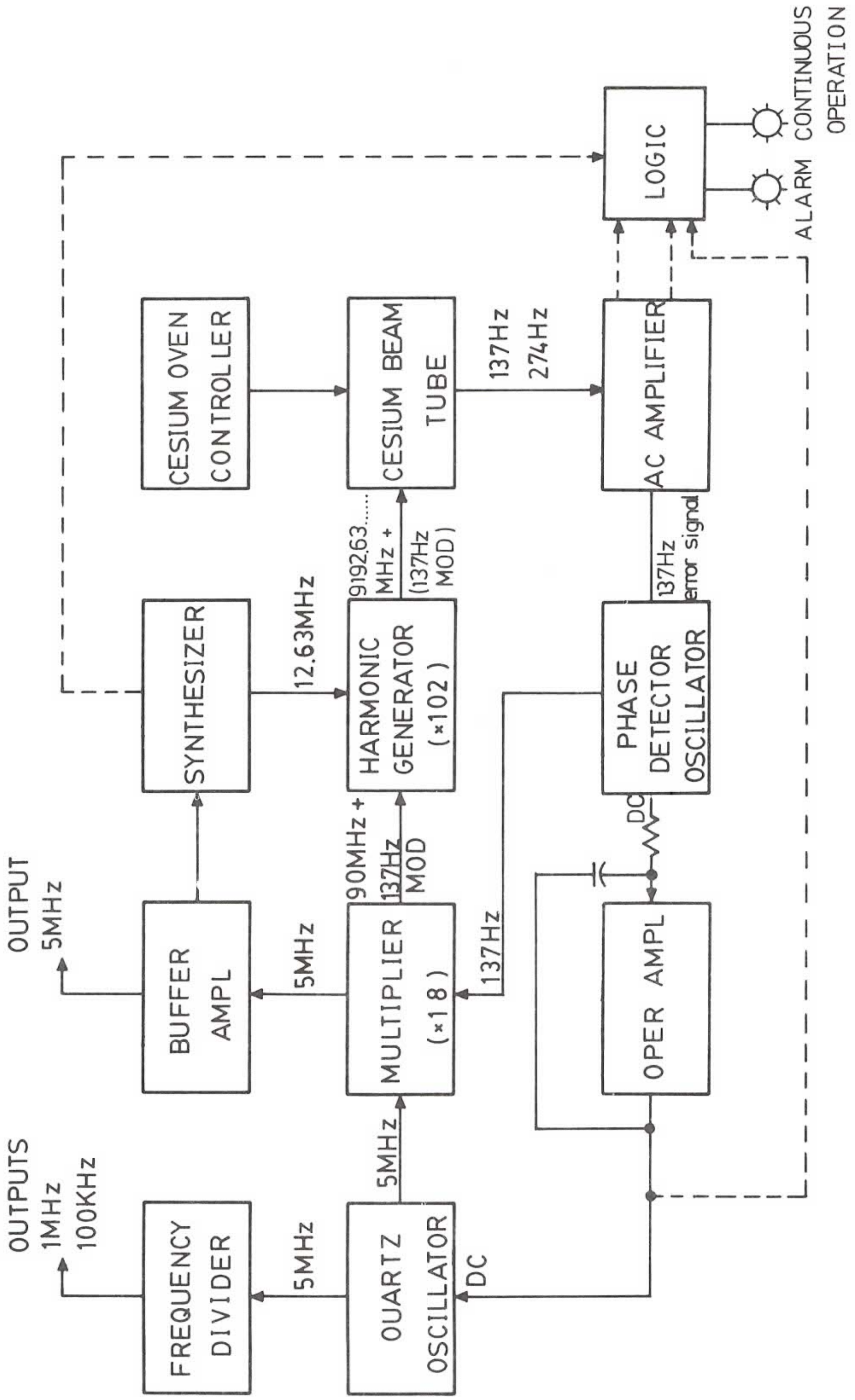


Fig.1 Simplified Block Diagram of Cs Beam Frequency Standard

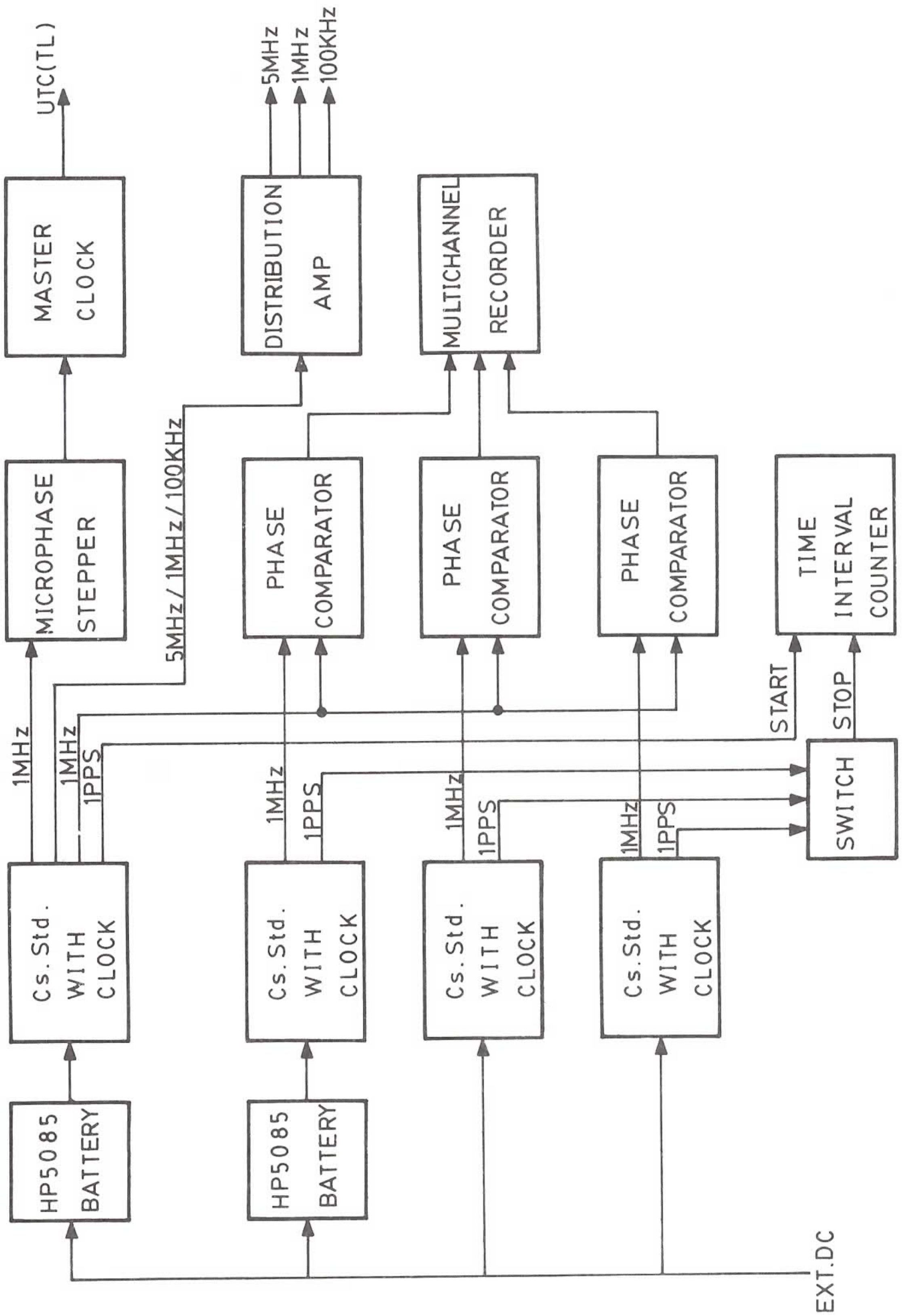
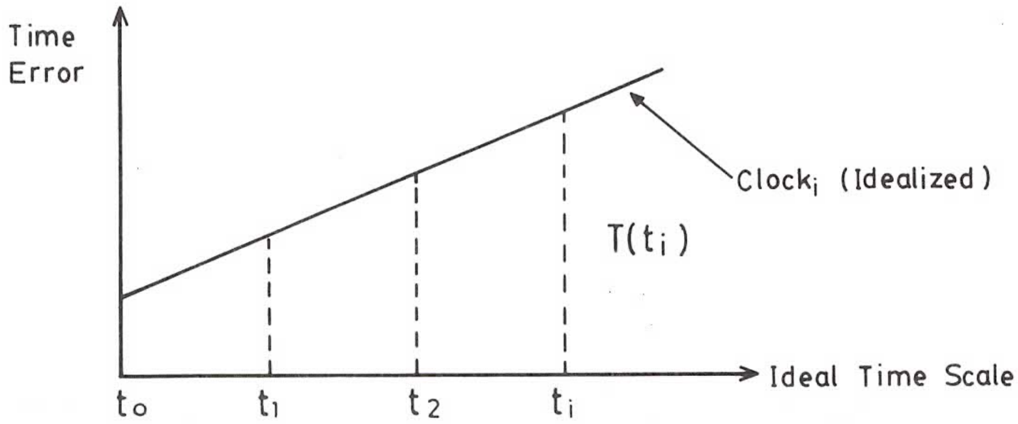
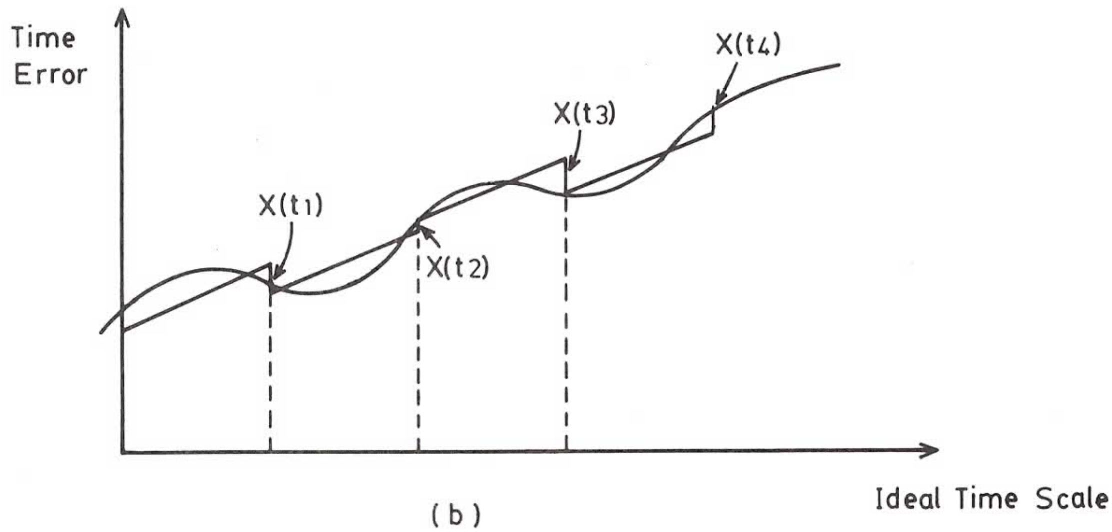


Fig.2 Time And Frequency Standard of Telecommunication Labs.



(a)



(b)

Fig. 3 (a) Idealized Clock
(b) Physically Realizable Clock

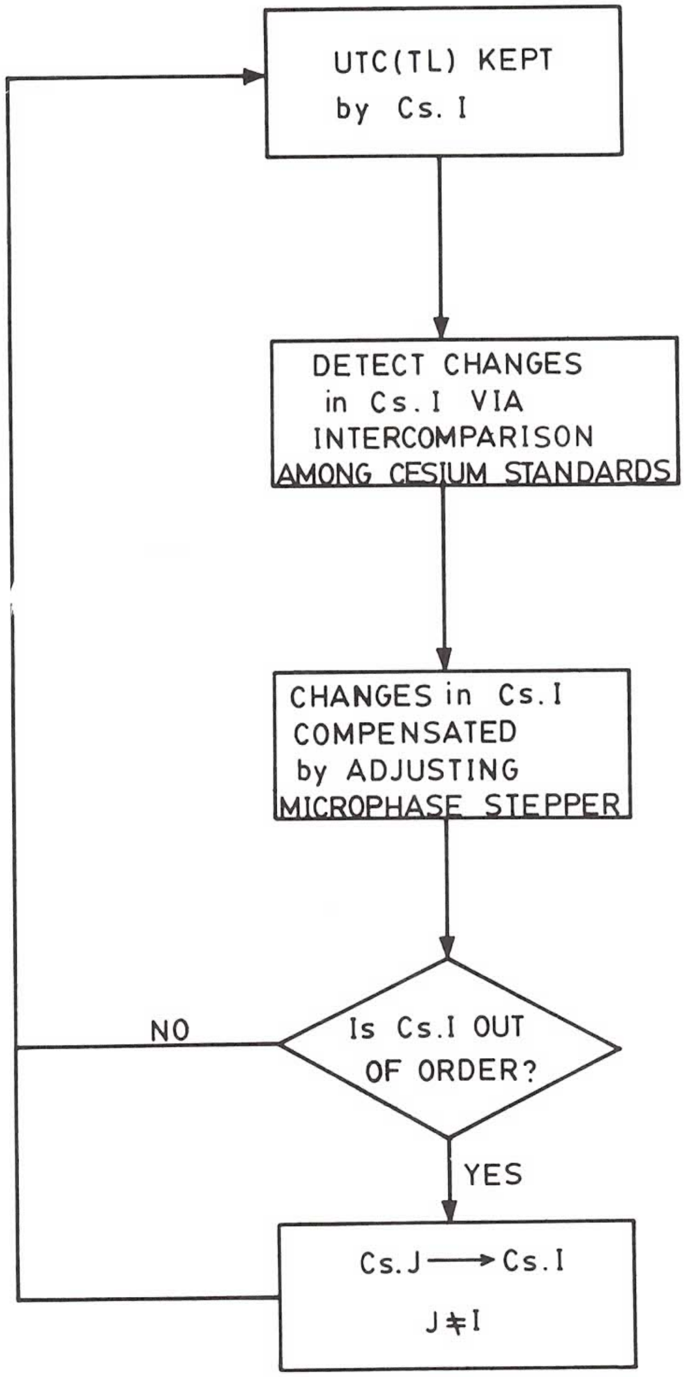


Fig.4 UTC(TL) Time Generution

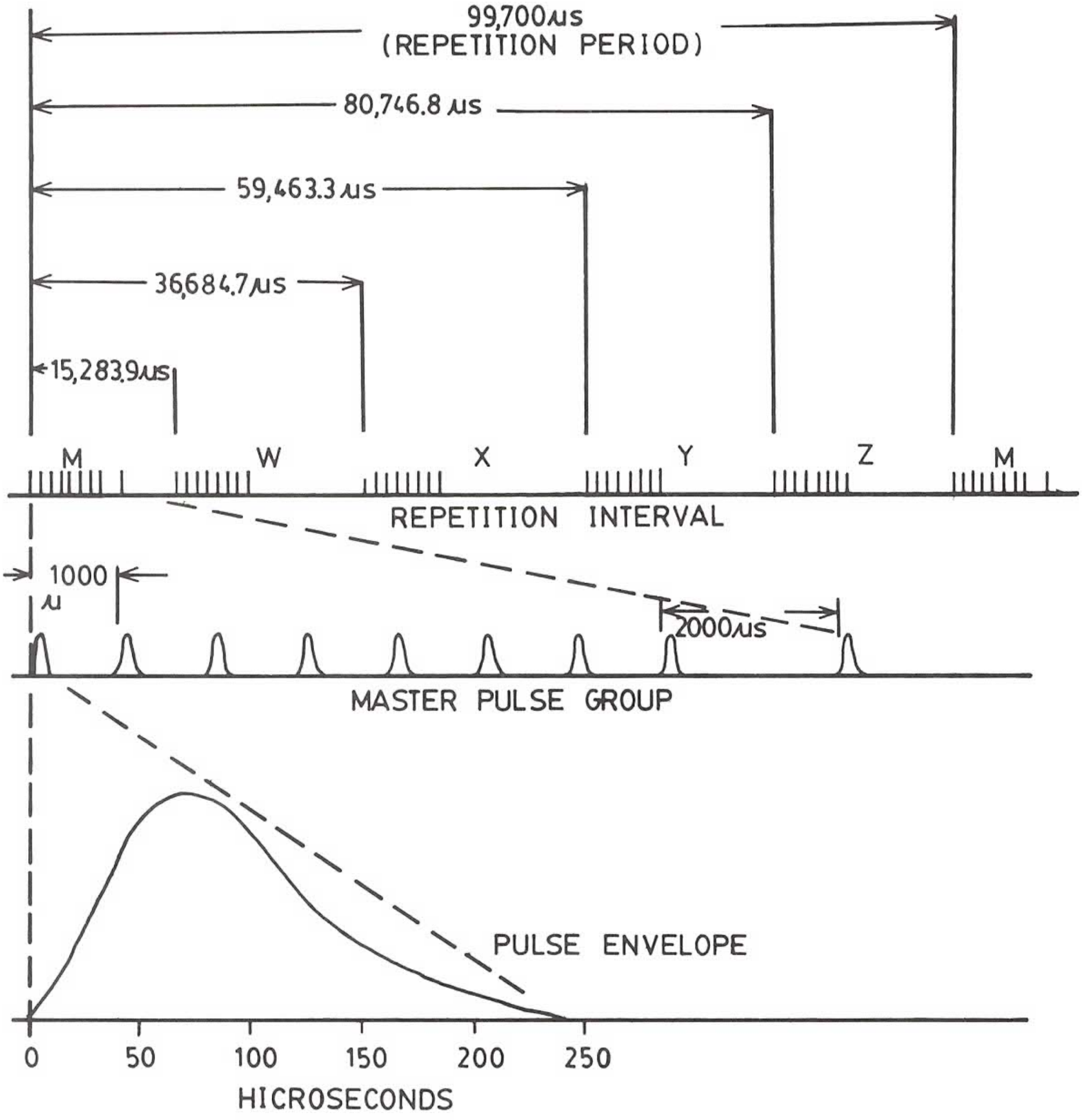


Fig.5 The Northwest Pacific LORAN-C Chain

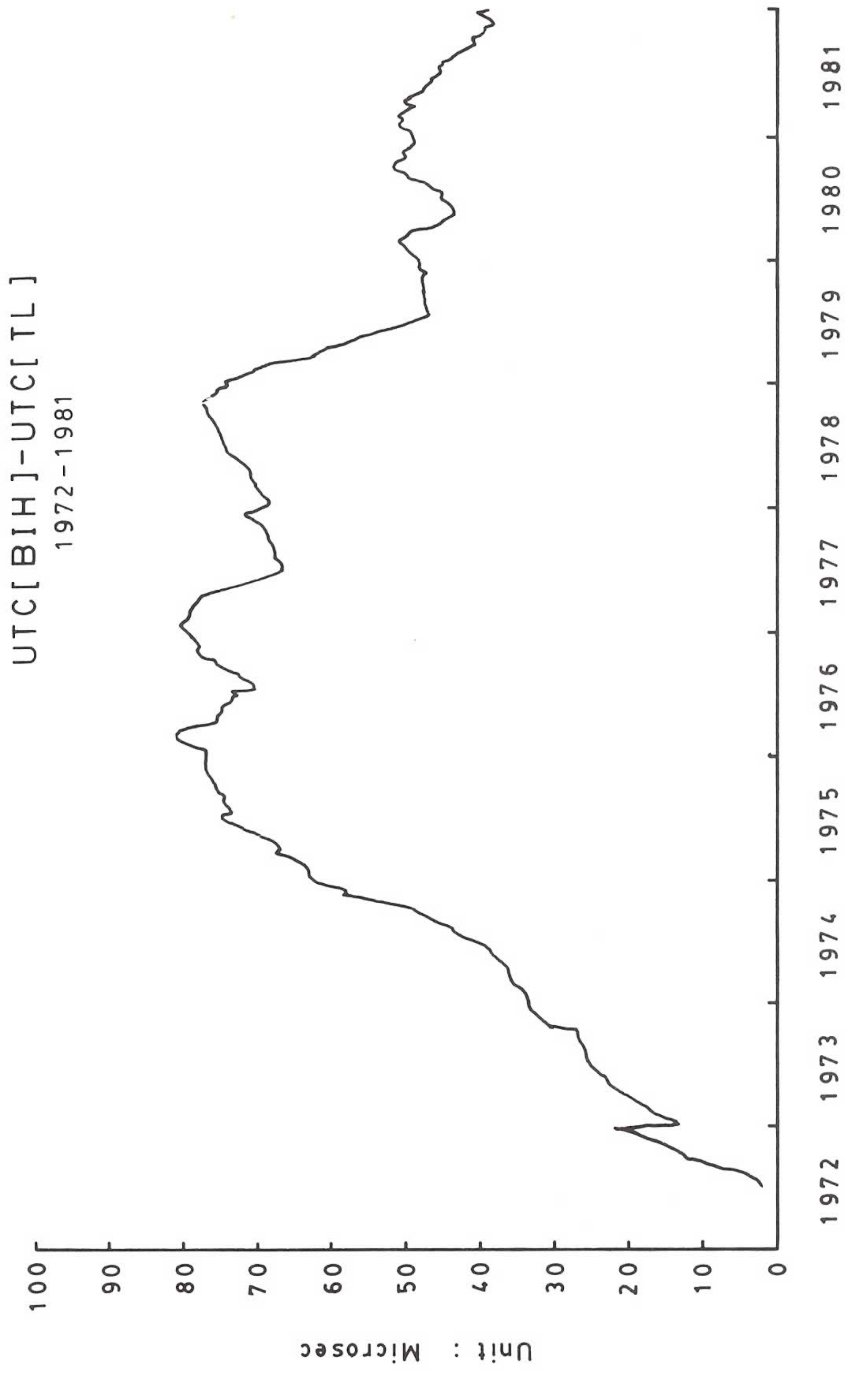


Fig.6 Time Differences Between UTC(BIH) and UTC(TL) from 1972 to 1981

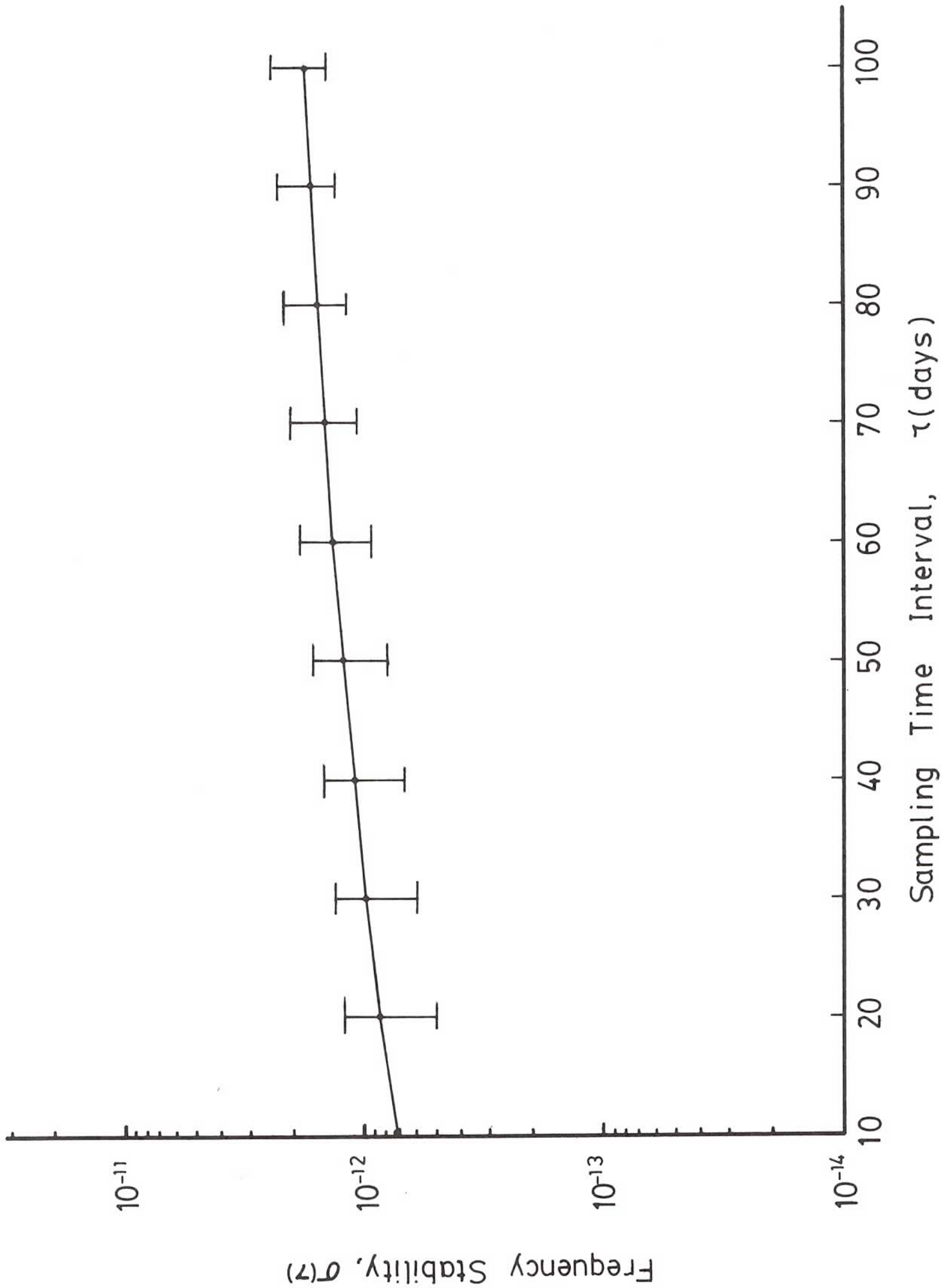


Fig.7 Frequency Stability of UTC(BIH) - UTC(TL)