5-4-2 Frequency Standards Calibration System and Remote Calibration System

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A frequency standard is used by many companies, laboratories and factories. It is very important to calibrate the frequency standard regularly so that it can trace in the SI units to stabilize quality. The Communications Research Laboratory has been providing frequency calibration services based on the Japanese Radio Law. One of these calibration services is accredited with the ISO/IEC 17025, which is called the ASNITE-NMI accreditation service. Another new calibration service was started in April 2003, which is a calibration service under the Japanese Measurement Law. Our calibration services are now only being provided for calibration in CRL's calibration room. However, the demand for a remote calibration system has increased. In this paper, we present details on our frequency calibration systems and briefly report of our remote calibration system, which is currently being developed.

Keywords
Frequency standard, Global MRA, ASNITE-NMI accreditation service, jcss calibration service, ISO/IEC 17025

1 Introduction

Frequency standards are used in many enterprises, research institutes, and manufacturing plants. To stabilize the quality of products and results in these contexts, it is very important to ensure, through regular calibration, that the frequency standard provided is traceable to the SI unit system.

As the organization responsible for the national frequency standard, the Communications Research Laboratory (CRL) determines a national standard frequency that is precisely traceable to the SI unit system. Using this national standard frequency, the CRL has provided, as of February 2003, two calibration services. The first consists of instrument calibration for specified calibration organizations and qualified businesses conducting radio-station checks based on Radio Law 102-18 and on the Rules for Qualified Calibration Service Providers; this calibration is referred to below as "calibration for qualified calibration service." The second service consists of instrument calibration under general contracts based on the Communications Research Laboratory Independent Administrative Institution Law 10-5 (hereinafter, "contract calibration"). Additionally, since April 2003, CRL has provided an additional calibration service (jcss calibration) based on the Traceability System set forth in the Measurement Law. Because the CRL's calibration uses the national standard frequency directly as the reference for calibration, this calibration is directly traceable to the SI unit system.

Meanwhile, as described in **5-4-1**, the CRL is required to participate in the Global MRA to provide frequency standard calibration services. To meet the requirements of the Global MRA, the calibration service must be traceable to the SI unit system and must comply with the ISO/IEC 17025 standard. Accordingly, we have established a frequency calibration system that meets ISO/IEC 17025 requirements for contract calibration services. This system has been in full-scale operation since January, 2001.

The calibration service the CRL now provides is referred to as "carry-in calibration," in which the user brings a frequency standard to the CRL and compares its frequency with the national standard. This method presents some problems; for example, the user cannot use the frequency standard during the calibration, and the calibration results are those obtained only under the measurement conditions of the CRL (and are thus strictly valid only for operation at the CRL). There is a growing need for a remote calibration system that allows the user to maintain its frequency standard on-site, allowing for calibration under the user's operating conditions.

AT the same time, the CRL is working to establish a system for the secure distribution of UTC (CRL) that will be traceable to the international standard, to meet public demand in connection with applications such as time stamping. This system will also require a distributed time-distribution system as well as a remote time synchronization system that will work with standard time.

To meet these needs, the CRL has begun to develop a remote calibration system that can supply and calibrate time and frequency data for remote sites.

This paper describes the currently operating "carry-in" calibration system and the remote calibration system under development.

2 Carry-in calibration system[1]-[3]

The carry-in calibration system has four service menus for the following measurement items (as of April, 2003).

- Frequency accuracy
- Short-term stability
- Long-term stability
- Reproducibility

In the frequency accuracy calibration service, the accuracy of the user's frequency is measured. Regarding calibration, an essential requirement is for "a qualified calibration service," and this service is predominant among the CRL's current calibration offerings.

In the measurement of short-term and long-term stability, the stability of the frequency standard is measured over a certain time range. In the short-term test, measurements are taken at 1, 2, 5, and 10 sec, while in long-term testing, measurement is carried out over 30 days. The short-term stability check is a must in terms of calibration for "qualified calibration service providers." Because the long-term stability test takes at least 30 days to complete, no one has requested this service in the past several years. We may have to reconsider its usefulness.

In the reproducibility check, the reproducibility of provided values is measured after frequency accuracy calibration is completed and after power is shut off and turned on 24 hours later. There are several requests for this service per year.

Customers can select all services through contract calibration. Regarding calibration, it is now mandatory for "qualified calibration service providers" to receive annual frequency accuracy checks and short-term stability checks. The frequency accuracy check is the primary service in this context. This paper describes the frequency accuracy calibration system used in the contract calibration services, designed to conform to the ISO/IEC 17025 standard.

2.1 Frequency accuracy calibration system

Table 1 Calibration system for frequency standards

Item	Specifications
Frequency	1 MHz, 5 MHz, 10 MHz
Input signal	Sinusoidal waves of the service signals or the corresponding national standard frequency
Reference signal (in the time interval method)	10 MHz national standard frequency
Accuracy of the max. freq.	$< 1 \times 10^{-14}$
Time for calibration	24hours

Table 1 shows the measurement items of the frequency accuracy calibration system under contract calibration, at 1, 5, and 10 MHz. The national standard frequency and one frequency of the device under test (DUT) to be calibrated are used for calibration. For frequency accuracy at each level, the frequency counter method is used when the frequency deviation is larger than 1×10^{-9}; when deviation is less than this the time interval method is employed. Calibration itself takes 24 hours and preliminary measurement and system check take about one day, so two days are required in total.

The calibration system is installed in a room maintained at constant temperature and shielded from electromagnetic waves, and calibration is performed at 23±1 °C and relative humidity of 50±10%.

As shown in Fig.1, the 5-MHz national standard frequency counter reference signal is used in calibration. Our system includes four calibration counters, and thus is capable of calibrating four DUTs at a time.

2.2 Calibration of frequency accuracy

To comply with the ISO/IEC 17025 stan-

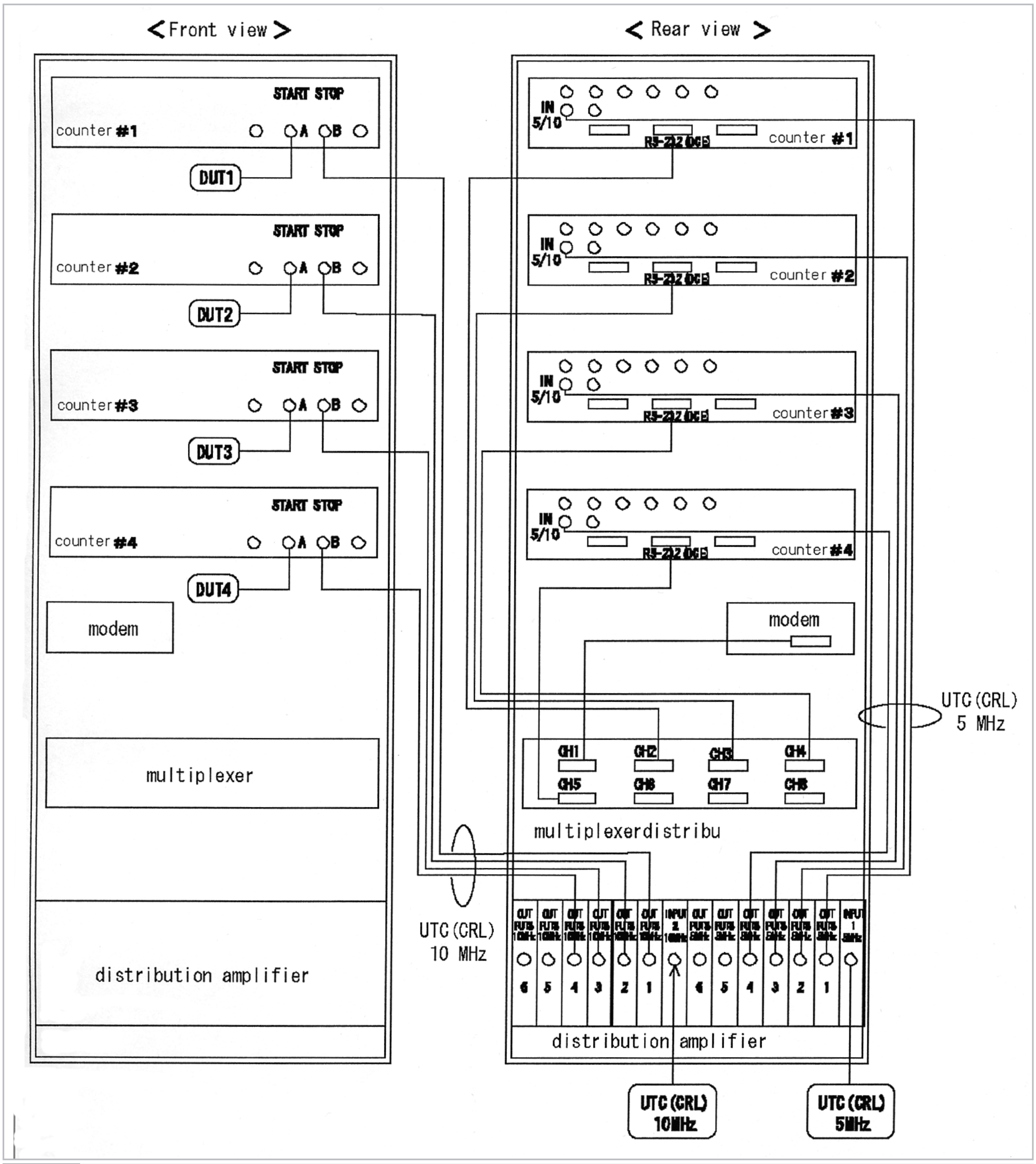

Fig.1 *Circuit diagram of the calibration system*

dard, all frequency accuracy checks are carried out based on steps outlined in a calibration work sheet. Fig.2 illustrates the calibration flow in the frequency accuracy check. The steps involved are roughly divided into three groups.

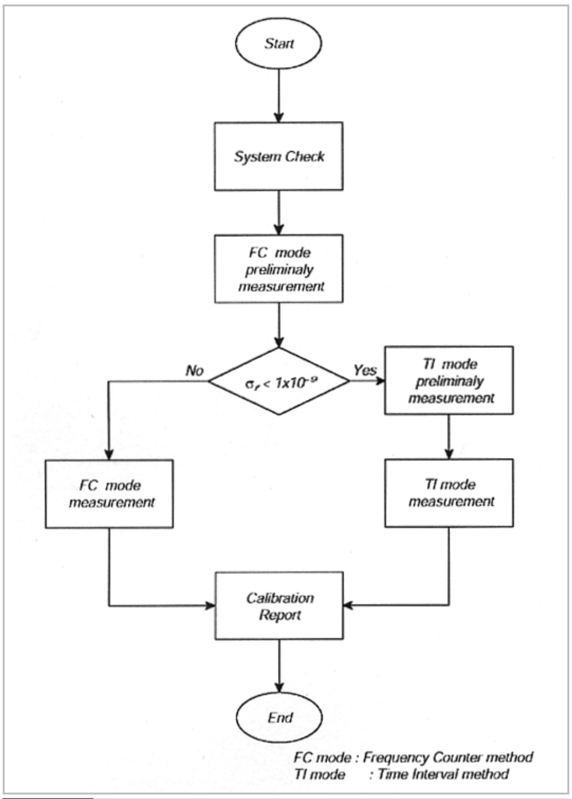

Fig.2 Flowchart of carry-in calibration

The first group forms the system check. The system check is conducted for each time interval under measurement to evaluate the calibration system and to ensure optimal performance.

The second group of steps consists of preliminary measurement. This is necessary to determine the measurement method and measurement parameters.

The third step is the calibration itself. A calibration certificate is issued based on this measurement data.

These individual steps are explained below, with reference to the flowchart.

2.2.1 System check

When a DUT is brought in and reception procedures are completed, the calibration shown in the process flow of Fig.2 starts. First, a national standard frequency of the same value as the frequency to be calibrated is connected to signal input 1 of the counter shown in Fig.1. The 10-MHz national standard frequency is connected to signal input 2.

First, measurement is carried out by the frequency counter method. In this measurement mode, frequency is counted with a gate time of one second, and measurement is carried out ten times at intervals of one minute. It takes about 10 minutes to complete this measurement.

If no anomaly is found in this measurement, the time interval method is then applied. This measurement measures the time intervals falling between the signals at input 1 and those in input 2. Measurement is made for 20 hours at intervals of 20 seconds. Because measurement under this method is performed with reference to two national standard frequencies, an uncertainty value is obtained for the user's overall measurement system.

The system check takes about 20 hours and 10 minutes. During the system check, the DUT is activated and kept in a room maintained at constant temperature.

If there is no anomaly in the measurement results, the frequency to be checked is connected to signal input 1 to start preliminary measurement.

2.2.2 Preliminary measurement

In preliminary measurement the frequency counter method is applied first. The frequency of the DUT is counted with a gate time of one second, and measurement is repeated ten times at intervals of one minute.

If the deviation of measured frequency is larger than 1×10^{-9}, the frequency counter is used in the main measurement, and if smaller, the time interval method is used. Usually, the frequency deviation of Rb and Cs frequency standards is smaller than 1×10^{-9}.

Since the input 2 signals, which serve as the time reference in the time interval method, are 10-MHz signals, cycle slips occur if the time intervals become longer than 100 ns.

This calibration system, however, can correct cycle slips automatically provided that five sets of sample data have been obtained before cycle slips begin to occur. Thus even in the time interval method, one hour of preliminary measurement is conducted at intervals of 20 seconds to determine the best sampling intervals, thus preventing cycle slips. When the ideal sampling intervals are found, main measurement is initiated.

2.2.3 Main measurement

After the preliminary measurement is over, main measurement begins automatically. In the frequency counter method, measurement is carried out for 24 hours at intervals of one minute, with a gate time of one second. In the time interval method, in turn, the time intervals are measured at the sampling intervals determined in preliminary measurement, and measurement is performed for 24 hours.

After the main measurement is completed, the acquired data is subject to statistical processing and the data is transformed into six consecutive 4-hour data sets. Then we calculate the frequency deviation of the 4-hour data and calculate standard deviation σ from the six obtained frequency deviations. As the sample number is 6, the degree of freedom n-1 is 5. Multiplying this standard deviation by the coverage factor k=2.6, we obtain k$x\sigma$, the expanded uncertainty value for the tested DUT. A calibration certificate is produced based on these results.

2.2.4 Controllers

Calibration is carried out following the steps outlined in ***2.2.1*** to ***2.2.3*** above, and a calibration certificate is prepared. These procedures are executed virtually automatically, using PCs. Fig.3 shows the controller for our calibration system.

The only operation conducted manually during calibration is the switching of signals at signal input 1 at the beginning of the step in ***2.2.2***. Otherwise, the operator is required only to enter a confirmation command into the PC console at each step of the process to confirm that no errors have occurred.

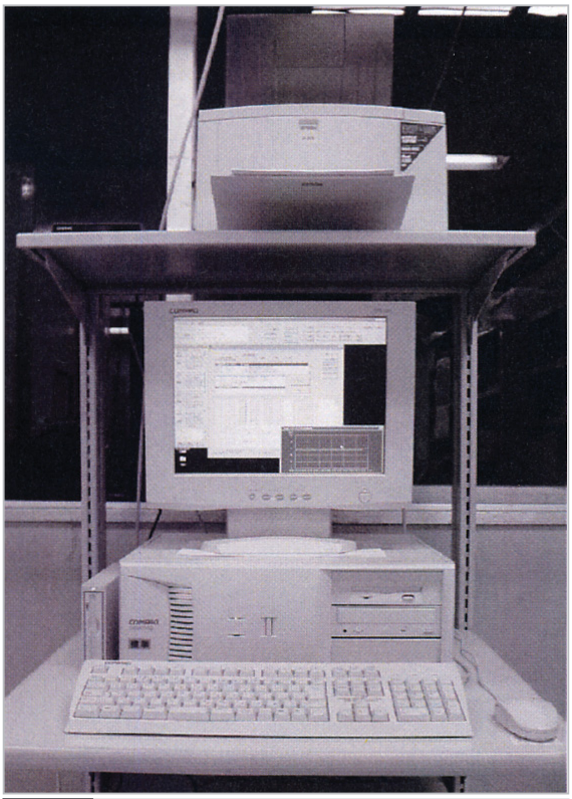

Fig.3 Calibration system controller

The purpose of such automation is to minimize human error and eliminate irregular tasks, such that the calibration process will comply with the ISO/IEC 17025 standard. Automation provides another advantage in that calibration may be completed in two days if no problem arises (system check of 20 h 10 min, preliminary measurement of 10 min (or 10 min + 1 h, in the case of time interval method) 24 hours of main measurement plus a certain amount of time for switching and miscellaneous operations). Through automation, planning of calibration schedules and explanations to customers become easier.

2.3 Current conditions and future challenges of the carry-in calibration system

Among the carry-in calibration services we provide, the frequency accuracy check by contract calibration was approved as ISO/IEC 17025 compliant in January, 2003 by the Incorporated Administrative Agency, the National Institute of Technology and Evaluation, subsequently gaining ASNITE-NMI accreditation. In addition, the CRL was authorized by the Ministry of Economy, Trade and Industry to conduct jcss calibration in April, 2003. With the two above-mentioned accreditations, the CRL can now issue calibration certificates that are valid both internationally (ASNITE-NMI accreditation) and domestically (jcss calibration).

Nevertheless, we must improve our calibration techniques further in order to maintain the overall quality of our calibration service. Currently, in jcss calibration, the CRL applies a greater number of measurement cycles and sets the coverage factor k to 2.0, resulting in expanded uncertainty values that are lower than would otherwise be obtained. This method is, however, only applied to DUTs on a case-by-case basis. Our plan is to apply this calibration method used in jcss to our entire calibration system, once the testing system moves into its new facilities.

The calibration service menus must also be subject to review in order to improve the carry-in calibration system. Currently, we provide the four calibration services described in section 2 above, but these are limited to frequency-related services. Meanwhile, the CRL, in its capacity as custodian of Japan Standard Time, is naturally expected to provide time calibration services. We are therefore conducting preliminary tests in connection with the addition of a time calibration service and time interval calibration service. The relevant measurement techniques have been nearly established, and the new services will be officially added to the original offerings after user needs have been assessed. The time calibration service will of course be compliant with the ISO/IEC 17025 standard and will be registered in the Global MRA.

Additionally, we must review the long-term stability verification service, for which we have received no service requests in the past several years.

3 Remote calibration system[4]-[6]

We began development of a remote calibration system in FY2001. This remote calibration system has been developed to conduct the following three tasks:

- Remote frequency calibration
- Remote time calibration
- Synchronization of distributed standard time

The first two items represent the application to remote areas of carry-in calibration services registered in the Global MRA. We will work to register these remote services in the Global MRA as well.

To increase the reliability of the standard time distribution system for electronic time stamping, we are investigating a new system of disseminating distributed standard time.

The third item involves focusing development efforts on the establishment of a means of synchronizing distributed standard times using the remote calibration system.

3.1 Overview of remote calibration system

Fig.4 illustrates the concept behind the remote calibration system. The system uses the GPS common view method for the measurement of time difference and also employs one of the following two GPS receivers, depending on the user's accuracy requirements.

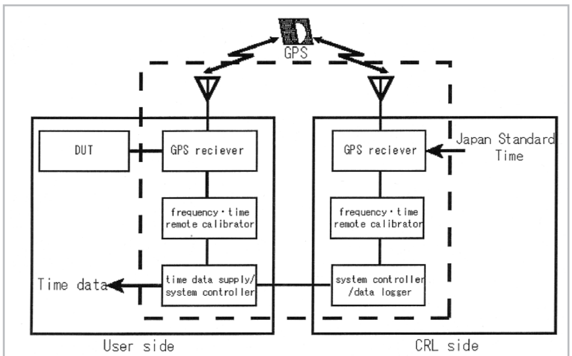

Fig.4 Overview of remote calibration system

(i) L1 C/A code multi-channel receiver
(ii) L1, L2 2-frequency multi-channel receiver

Receiver (i) is used for general carry-in calibrations requested by customers who do not require high accuracy. Although several commercialized receivers may be used, compactness and low cost are essential requirements in any remote calibration system. We have developed an L1 C/A code-based affordable receiver that can receive signals from eight GPS satellites at a time.

Receiver (ii) is used for highly accurate frequency/time calibrations and for standard time dissemination. This service therefore uses a 2-frequency receiver for precise positioning. This receiver has 40 channels, and is capable of communicating with up to 20 satellites even when receiving L1 and L2 frequencies. Through the concurrent reception of two frequencies, ionospheric delay can be corrected based on comparative measurement.

Table 2 shows the expected calibration uncertainties (nominal values) corresponding to the two different receiver types. Because the tolerance of frequency calibration is not proportional to that of time calibration in the two receivers, the values on this list represent minimum requirements. In the more affordable receiver, strict tolerances are set for time calibration, while in the high-precision receiver frequency calibration is designed to even more precise specifications.

Table 2 *Calibration uncertainty of two GPS receivers*

Multi-channel receiver	frequency calibration	time calibration
L1 C/A code	$< 1 \times 10^{-12}$ @ 1day	< 50 ns
L1/L2 two-frequency	$< 1 \times 10^{-13}$ @ 1day	< 20 ns

3.2 Experimental remote calibration system

Our remote calibration system is still in the development stage, and current specifications are only provisional. Fig.5 shows the experimental remote calibration system under development.

In the figure, the high-precision receiver is at the top left, and the affordable receiver is at the top right. In the lower left is the frequency counter used in the high-precision receiver to measure time difference. A data logger is shown in the lower right; this device is used to obtain environmental data required for compliance with the ISO 17025 standard.

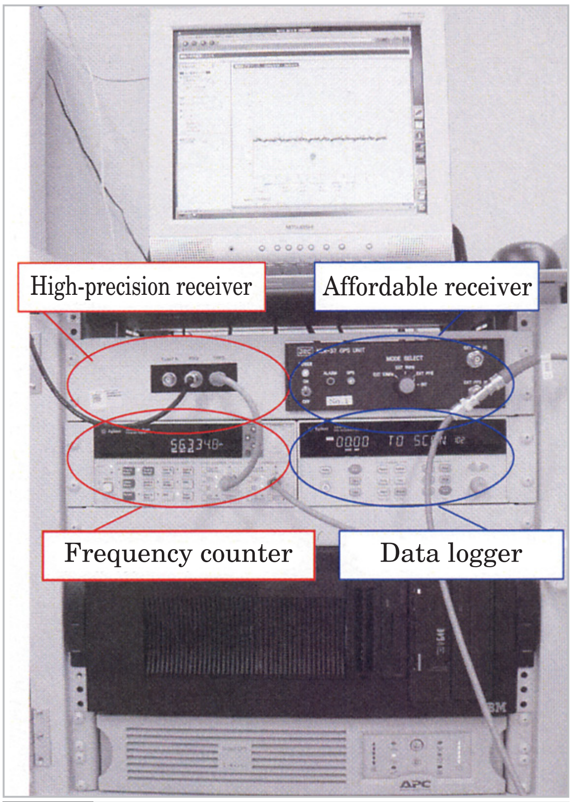

Fig.5 *Experimental system for remote calibration*

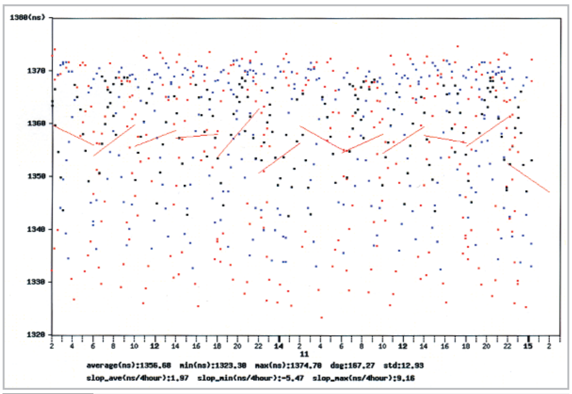

Fig.6 *Example of comparison tests*

Fig.6 shows an example of an experiment in which data received by the CRL using the affordable receiver was compared with GPS data received in Hachioji. Fig.6 shows the data acquired when the GPS elevation angle was at least 30 degrees: data for angles greater than or equal to 65 ° is shown in black; data for 45 – 65 ° is shown blue, and data for 30 – 45 ° is shown in red. Based on this data, we calculated frequency deviations every four hours, to arrive at values for mean frequency deviation and uncertainty. The mean frequency deviation was 1.36E^{-13}, and the expanded uncertainty was 1.58E^{-12}. These values fall within the predetermined specifications.

Here we do not show measurement results for time calibration because we did not correct for delay caused by cables and other factors; therefore we could not meaningfully determine an absolute time deviation value. However, the expanded uncertainty in 24h measurement was very low, at 34.2 ns.

We can now acquire measurement data falling mostly within the expected tolerances using the high-precision receiver. Nevertheless, we have not completed the performance check of the receiver itself and must subject the system to intensive field tests.

3.3 Current conditions and future challenges of the remote calibration system

The principal issue related to the remote calibration system is the delay in development, as pointed out in section **3.2**. A prototype to be installed in a remote area is currently under development, and will be ready for field tests to begin in May, 2003.

In the future we must clarify the regional dependence of the remote calibration system and the corresponding data uncertainty.

4 Conclusions

Carry-in calibration conditions and techniques have changed significantly in recent years. In fact, the two conventional calibration services—calibration for "qualified calibration service providers" based on the Radio Law and contract calibration based on the Communications Research Laboratory Independent Administrative Institution Law—were transformed into new services. The contract calibration service has evolved into the internationally approved ASINTE-NMI accreditation service (conforming to the ISO/IEC 17025 standard, as required for participation in the Global MRA). Since April 2003, we have provided a jcss calibration service that complies with the Measurement Law traceability system.

We must accelerate development of the ASNITE-NMI accreditation service in its new building in FY2004. To do so, we plan to improve the calibration system and expand our range of calibration services.

The remote calibration system is now the most important development item at the CRL, and we expect to commercialize the system as soon as possible.

Acknowledgments

We thank our predecessors at the CRL who have established its calibration services as would also like to thank the members of the Calibration Standardization Committee supporting the current calibration services.

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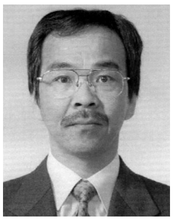

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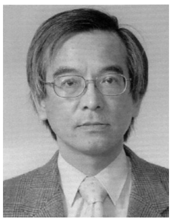

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