COMMISSION A: ELECTROMAGNETIC METROLOGY

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A1. Time and Frequency Standards and Time Transfer Technique

Communications Research Laboratory (CRL) has developed an optically pumped primary frequency standard CRL-O1 collaborating with NIST (Lee, et al., 1999), and achieved the accuracy of 1.5x10-14(Hasegawa, A., et al. 2000). CRL is now developing an atomic fountain type frequency standard (Fukuda et al., 2000b) and related technologies such as atom trapping, laser cooling, and laser stabilization (Fukuda et al., 1999, Kajita et al., 1998, 1999, Fukuda et al., 2000a, Tachikawa et al., 1999).

A small sapphire loaded resonant cavity for a hydrogen maser is analysed and its design has been optimized (Morikawa et al., 1999, 2000a,b). Using the sapphire loaded resonant cavity, a prototype small hydrogen maser has been developed and its performance has been evaluated (Morikawa et al. 2000c, 2001, Ito et al., 2001).

The effect of general relativity on precise time and frequency measurement has investigated and some interesting satellite orbits has been proposed (Hosokawa 2000a). A commercial Cs atomic clock was transported to a mountain and its frequency change due to gravitational red shift was detected using the GPS common view method. The result agreed to the theory of general relativity within the measurement error (Hosokawa et al. 2000b, Kotake et al., 2000).

Aiming to construct a new stable time scale using millisecond pulsars, which have good long-term frequency stability, CRL has developed a precise measurement system for millisecond pulsar timing, and continues the weekly observation from 1997. The results show the frequency stability is about 10-13 over one year period of time (Hanado et al., 1999 2000).

CRL is developing an international network of two way satellite time and frequency transfer (TWSTFT) in the Asia and Pacific region, and seven national timing centers in the region are take part in the network. The precision of the time transfer is about 0.2 to 0.3ns for five minute observation (Imae et al., 1999a, 2000b, 2001). CRL is also developing a new modem for TWSTFT, which enables simultaneous multi channel measurements and system delay calibration. The technology of TWSTFT is applicable to the time link between the clocks on a navigation satellite and on the earth. CRL is now developing a TWSTFT link system for the Engineering Test Satellite VIII (Imae et al., 2000a, Hosokawa et al., 2000d, Takahashi et al., 2000). NTT and CRL applied the two way time transfer technology to an optical fiber communication (SDH) system and achieved high precision time synchronization (Kihara et al., 2001).

Time stamping, which provides the reliability of the information on the internet, is a newly emerging need in the era of internet society. CRL is developing a trusted time serving system for Japanese time stamping authorities (Iwama et al., 2000b)

National Metrology Institute of Japan (NMIJ/AIST: formerly called NRLM) changed the evaluation procedure of the quadratic Zeeman shift in our optically pumped cesium frequency standard, NRLM-4, which has been operating as a primary frequency standard since February 1998 (Hagimoto 1999). The quadratic Zeeman shift is estimated from the frequencies of the neighboring Zeeman transition, which are about 70kHz from the clock transition. Formerly, we measured the Zeeman shift only twice after and before the continuous operation for TAI evaluation. Currently, the Zeeman shift is measured almost continuously. The new procedure is the repetition of the following 4 steps, (1)normal clock operation (about 7minutes), (2)measurement of the neighboring Zeeman transition frequency on high frequency side (about 30seconds), (3)normal clock operation(about 7minutes), (4)measurement of the neighboring Zeeman transition frequency on low frequency side (about 30seconds). During the steps (2) and (4), the local oscillator is not controlled, i.e., free running. Degradation of frequency stability due to the free running period was negligible, since the local oscillator was sufficiently stable in short time of 30s. Figure 1 shows an example of the behavior of the Zeeman shift. The fructuation of the order of 0.0001 Hz which corresponds to the shift of 10-14 was observed. It seems to be due to the temperature dependence of the current source to generate G-field. In principle, the G-field can be stabilized by servo-mechanism. However, at present, it is not controlled and the correction of this shift is based on the average for operating period.

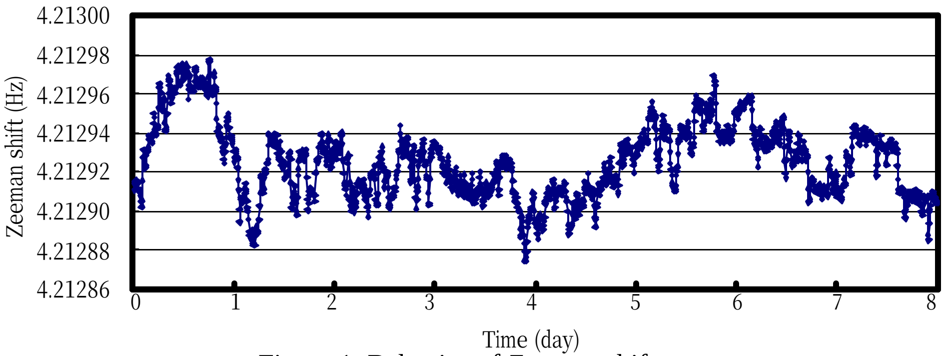

Figure 1. Behavior of Zeeman shift.

We have been measureing the duration of TAI scale interval using NRLM-4. Our procedure consists of the following steps. (1) We measure the microwave-power-dependent frequency shifts in opposite Cs beam directions, and determine the difference of the cavity phase shift as quickly as possible, before the hydrogen maser drifts. (2) After that, NRLM-4 is operated continuously for at least 5 days at the optimum microwave power without changing the operational parameters, and compared with the master clock (HP 5071A), which is linked to TAI. Our results are shown in Fig.2. The vertical axis denotes the value of $(u_{UTC}-u_0)/u_0$, where u_{UTC} and u_0 are the lengths of 1 second of TAI and the primary standard, respectively

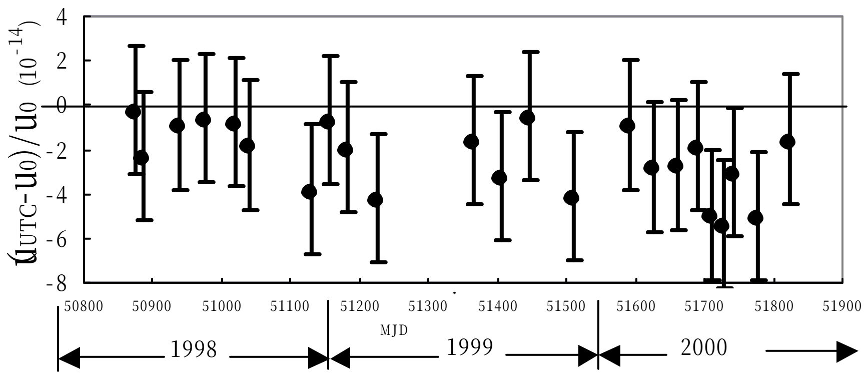

Figure 2. Calibration of TAI by the primary frequency standard, NRLM-4.

In November 2000, we had to move to a new building and we had taken NRLM-4 apart to pieces and has been overhauling it. We expect to NRLM-4 to operate with smaller uncertainty in the new laboratory with better environment after reconstruction and re-evaluation of uncertainty.
Last year, our laboratory had to move to a new building and the experiment using a vacuum system had been interrupted. The new laboratory was at the level of B3F under the ground, where good temperature stability was expected. We manufactured a TE_{011} microwave cavity for Ramsey interrogation and another TE_{011} cavity for the state selection. Both cavities had a Q of 15,000 and are adjusted their resonance frequencies same within 100 kHz. They have no elements for tuning and can be tuned to the resonance frequency of Cs only by temperature. As a source for exciting the 9.192631 GHz transition of Cs, we developed two microwave oscillators using a dielectric resonator oscillator (DRO) and a sapphire loaded cavity oscillator (SLCO), respectively. Both oscillators were frequecy stabilized by a 10 MHz reference signal that was produced by a frequency synthesizer based on a H-maser. They showed similar short-term stability when locked to the H-maser. We controled the 10 MHz frequency through the synthesizer to stabilize the 9.192631 GHz frequency to the Cs fountain. In this way, we could obtain 10 MHz standard frequency that was stabilized by the Cs fountain. The short term stability of the standard frequency was measured to be 10^{-13} at t=10 s by means of the phase comparison with another H-maser.

A2. Laser Stabilization and Frequency Measurement

National Metrology Institute of Japan (NMIJ/AIST: formerly called NRLM) has been developing several stabilized lasers and an optical frequency measurement system by means of an optical frequency comb generated from an ultra-fast mode-locked Ti: Al_2O_3 (TiS) laser. We could measure optical frequencies of these stabilized lasers by the frequency measurement system and reported results at the working group of mise en pratique (MeP) in the Consultative Committee for Length (CCL) of the meter convention.

The periodic pulse train of a mode-locked laser can be described in the frequency domain as a comb of spectral lines equally separated by the pulse repetition frequency f_{rep}. This frequency comb has been applied for measurement of the frequency intervals in the optical region (Udem et al. 1999). The spectral bandwidth of an ultra-fast mode-locked Ti: Al_2O_3 (TiS) laser can be coherently broadened over one-octave by self-phase modulation in a photonic-crystal (PC) fiber (Wadsworth et al. 2000). A direct comparison between microwave and optical frequencies has been realized by using the one-octave optical frequency comb (Diddams 2000, Jones 2000, Holzwarth 2000). We started a project to realize a direct comparison between microwave and optical frequencies by using an ultra-fast mode-locked laser.

We developed a system of direct comparison between microwave and optical frequencies by using a frequency comb generated from an ultrafast mode-locked laser and broadened over one octave with a photonic crystal fiber [Sugiyama et al. 2001a and 2001b]. The mode-loccked laser is made by Femtolasers (Austria). It is dispersion-controlled by only chirped mirrors, and its repetition rate frep is 150 MHz. We can select two type of spectra by position of a Ti: Al_2O_3 crystal. We used a photonic crystal fiber (Core diameter: 2.5 mm, Zero-GVD wavelength: 800 nm) made by University of Bath (UK).

We measured the frequencies of three stabilized lasers [Sugiyama et al. 2001b].
(a) Iodine-stabilized Nd:YAG laser at 532 nm, NRLM-Y3 with an uncertainty of 0.34 kHz.
(the a10 component of the $^{127}I_2$ 32-0 R(56) transition)
(b) Iodine-stabilized He-Ne laser at 633 nm, NRLM-P4 with an uncertainty of 1.1 kHz
(the f component of the $^{127}I_2$ 11-5 R(127) transition)
(c) Rubidium two-photon stabilized ECLD at 778 nm developed by Nakagawa et al.
(^{85}Rb 5S $_{1/2}$ (F=3) - 5D $_{5/2}$ (F=5))

Based on these measurements, we could report followings at the MeP WG:
(a) The frequency value of NRLM-Y3 (iodine-stabilized Nd:YAG laser, 532nm) [Sugiyama et al. 2001b],
(b) The frequency value of NRLM-P4 (iodine-stabilized He-Ne laser, 633 nm) [Sugiyama et al. 2001b],
(c) The frequency value of absorption molecule $^{13}C_2H_2$ P(16) transition [Sugiyama et al. 2001b ,Nakagawa et al. 1996,and Onae et al. 2001].

We also reported results on iodine transitions at the MeP WG:
(d) The frequency intervals of iodine transitions near 532 nm [Zhang et al.],
(e) The hyperfine structures of iodine near 532 nm [Hong 2000, Hong 2001, Hong].

We developed stable and widely-tunable, continuous-wave optical parametric oscillators (cw-OPOs) [Ikegami et al. 2000, Ikegami et al. 2001] and realized a phase-coherent optical frequency division by 3 of 532nm laser light from a Nd:YAG laser, which produced 798nm and 1596nm light phase-locked to 532nm light [Slyusarev et al. 1999]. In addition, we constructed the optical frequency interval bisection system to produce a phase-locked 912nm light whose frequency is the average of those of 798nm and 1064nm light [Slyusarev et al. 2001].

A3. Realization of Electrical Units

A quadrature bridge has been developed in ETL (former NMIJ(National Metrology institute of Japan)) with the aim of determining capacitance values at several frequencies in terms of a resistance ultimately derived from the QHR. The bridge is evaluated by comparing a 1 nF capacitor with a 100 k? resister at six frequencies from (3/8x10/2?) kHz to 10/2? kHz [Nakamura,Y. et al., 1999].

A quantized Hall resistance (QHR)-based capacitance measurement has been developed. The chain comprises an ac resistance bridge together with an ac-dc calculable resistor, a multi-frequency quadrature bridge enables the measurement of the frequency dependence of capacitors in the range between 1-1.592 kHz. The results demonstrate that the frequency dependence of 10-pF standard capacitors can be measured based on the QHR with a relative standard uncertainty of $3x10^{-8}$ [Nakamura, Y. et al., 2001].

The thermoelectric transfer difference of Thermal Converters (TCs) can be evaluated in both current mode and voltage mode, using a fast-reversed dc (FRDC) source. Some types of TCs show differences in the thermoelectric transfer difference between voltage and current mode as large as some parts in 10^6. In order to investigate the origin of the discrepancy, the change of the thermoelectric transfer difference with the value of a resistor in series to the thermal converter has been measured with collaborating ETL, PTB, and NML. The result was in good agreement with an assumption that the Seebeck effect in the heater/heater support junction is the main source of the voltage transfer difference [Takahashi, K. et al., 1999].

Digital to analog converters based on the Josephson effect are promising for ac voltage standards because they produce voltage steps with ultimate precision and stability. ETL people are currently developing an SFQ-Based D/A converter, designed for synthesizing sinusoidal waveform for metrological applications. In this paper, we examine feasibility of an ac-dc transfer difference measurement for a thermal converter using the SFQ-Based D/A converter [Sasaki, H. et al., 2001]

A voltage divider has been developed in ETL to calibrate dc voltages up to 1 kV. The ratio of the divider can be automatically self-calibrated. The expected uncertainty is several parts per 108 for the self-calibration of voltage ratio of 1 kV to 1 V [Sakamoto, Y. et al., 2000]

A Single electron tunneling (SET) transistor was fabricated in ETL for metrological application. Gate modulation for a single electron transistor was observed. TLF-type noise was also observed which depend on cooling time [Iwasa, A. et al., 2000].

A4. EM Field, Power Density and Antenna Measurement

Three international symposiums related to EM Field, Power Density and Antenna Measurement were held in this period. They are International symposiums on electromagnetic compatibility in 1999, Conference on Precision Electromagnetic Measurements in 2000 and Asia-Pacific Radio Science Conference in 2001.

In EMC '99 the transmission scattering parameter between two dipole antennas above a finite ground plane are calculated by using the hybrid method of the geometrical theory of diffraction and the moment method. The S-parameters were measured by using a network analyzer calibrated by the TRL procedure [Fujii et al, 1999]. Also the antenna arrangement for the calibration of biconical antennas is theoretically evaluated.[Suzuki et al, 1999].

In CPEM 2000 many researchers from national institutes submitted their papers [Conference digest of CPEM]. An open-area antenna test site for measurement of standard antennas in ETL was introduced.. It has a ground plane whose dimension is 50m long by 30m wide [Komiyama et al, 2000]. Site insertion loss measured at five open-area test sites (OATS) were compared with the predicted values at four typical frequencies. In addition to the four frequencies, site insertion losses were measured at twenty-four frequencies for the frequency range from 30 MHz to 1000 MHz. These measurements were also compared with the predicted values and the measurements made by the NPL. The differences between ETL and NPL were within 0.8 dB. Antenna factors derived by the three-antenna method at five OATS are also compared [Morioka et al, 2000]. The details is published in [Morioka et al, 2001a]

Further, the measurement and comparison respecting antenna factor valuation are made in AP-RASC 2001[Komiyama et al, 2001]. A method to calculate AFs of a dipole antenna by a single site insertion loss measurement is proposed. The numerical and measurement results are compared. It said that the method is also applicable to a dipole antenna with a balun, whose characteristics cannot be predicted [Morioka et al, 2001b].

The S-parameter between two dipole-elements on a ground plane is measured using a network analyzer with its TRL (Thru-Reflect-Line) calibration. The S-parameter is also calculated by the method of moment and compared to the measurement results. The comparison shows that the calculated S-parameter is usable as a reference value in the evaluation of CAF (Complex antenna factor) measurement sites. [Fujii et al. 2000]

Normalized site attenuation (NSA) using a pair of biconi-log antennas is calculated in horizontal and vertical polarizations using the method of moment. The calculated results are confirmed by a comparison with experimental results. From the results, it is concluded that correction for the biconi-log antennas is difficult in the NSA measurement. [Fujii et al. 2001a]

The transmission S-parameter between dipole elements on a rectangular finite ground plane is calculated by the Method of moment (MoM) with planar-segments in the horizontally and vertically polarized configurations. The results are compared to the calculated results with the measured results with a TRL-calibrated network analyzer. The results show that the size of the finite ground plane for the vertical polarization should be much larger than for the horizontal polarization. [Fujii et al. 2001b]

In order to examine the waveform reconstruction technique using the CAF in the near-field measurements, the magnetic field radiated from a monopole antenna excited by pulsed input voltage was reconstructed and compared with calculated results. It is shown that the reconstruction technique using the CAF can be used in the examined geometry. [Hamada et al. 2001]

A method for finding the direction of arrival (DOA) of a single short pulse is proposed. The method is based on a waveform reconstruction technique using complex antenna factors (CAF). Since the frequency characteristics of CAF have angle dependency, the DOA of an electromagnetic pulse can be determined by the waveforms reconstructed with CAF. The result of an experiment shows the possibility to apply the two-dimensional DOA finding. [Ishii et al.

2000]

A method to design an electromagnetically coupled microstrip slot antenna for field measurements is proposed. The method is based on an equivalent circuit approach, where the slot part of the antenna is analyzed by the FDTD method and the stub part is regarded as a transmission line. A slot antenna is designed using the proposed method in 2-10GHz. [Suga et al. 2000]

A novel method for image reconstruction of a microwave hologram synthesized from one-dimensional data is proposed. An equivalent diffraction is introduced in order to obtain better images than the Fresnel approximation. An experiment made at 10 GHz shows the usefulness of the proposed method. [Hasegawa, T. et al. 2000]

A5. Power, Attenuation and Impedance Measurement

An automatic calibration system for a broadband RF power meter was developed in the frequency range from 10 MHz to 18 GHz for the APC 7 connector with a 7 mm coaxial waveguide [Inoue, T., 2000]. This system is composed of an isothermal control type dry calorimeter, a broad band stabilized signal source and a controller. Measurements are easily performed by a graphic programming method. RF power is measured directly by the calorimeter and the calibration factor is determined by connecting a device under test at the measuring port. The design, fabrication, basic characteristics and calibration experiments are described.

The evaluation of uncertainty of a broadband RF power calibration system were studied from 10 MHz to 18 GHz of 7 mm coaxial waveguide[Inoue, T. and Sato, K., 2000]. The formula of uncertainty and expression of the factors was derived from measuring equation. They were summarized to three tables of the DC substitution coefficient, the power splitting ratio and the calibration factor. As a result, the standard uncertainty of the calibration system became 0.1-0.21 % for the frequency range from10 MHz to 18 GHz. This is considered as the best uncertainty of the system. As an example a power meter was calibrated and the standard uncertainty of its calibration factor became 0.15-0.65 % in the full frequency range.

The effect of excess heating in calorimetric RF power measurement was analyzed using a short. Experiments have performed for two types of calorimeter of 10 MHz-18 GHz and 10 MHz-40 GHz. Reasonable correction coefficients were obtained for these cases and the method are found to be useful for evaluation of excess heating effect [Inoue, T., 2000].

A system, which automatically measures an effective efficiency of a bolometer mount in the frequency range of 75-110 GHz (W-band), was developed [Okano, Y. and Inoue, T., 2001]. It consists of a dry mono-load microcalorimeter and a broadband signal source. An automatic measuring algorithm was newly devised, and it has merit to shorten measuring time. Measurements of effective efficiency were carried out in the full band by 1 GHz intervals. Using this standard bolometer mount, calibration factors of a device under test (DUT) were measured for full range by a phase shift method, and were found to have small uncertainty due to the source miss match.

Inductive voltage divider (IVD) operating at 1 kHz, traceable to low frequency standard, is employed as the primary standard for microwave attenuation standard at NMIJ. In order to apply the IVD to intermediate frequency (IF) standard attenuator of IF substitution method instead of 30MHz piston attenuator, basic properties of heterodyne detection with IF of 1kHz is experimentally studied in frequency of 10GHz. System using this method can be expected to excel in an easy maintaining of precision, and an inexpensive running cost. As the result, the heterodyne detection gives an IF output in frequency stability of better than 0.03Hz/10min. and amplitude stability of 0.001dB/10min., and wide dynamic range of linearity. These properties are sufficient for precision measurements of microwave attenuation standard [Anton, W. and Kawakami, T., 2000].

Linearity of heterodyne detection is important in the IF substitution method. Influence of harmonic frequency signals on the linearity is analyzed. The analysis shows that the harmonic frequency signals attendant on the measurement frequency signal and change of the harmonic frequency signals derived from the local frequency signal affect attenuation measurement [Okano, Y. and Kawakami, T., 2000].

A new broadband microwave radiometer of the differential type has been made for microwave noise measurement by adopting a correlation scheme with a quadrature hybrid coupler (QHC) and without devices that limit the radiometer bandwidth [Nakano et al., 1999], [Nakano et al., 2000], and an electrically controlled broadband microwave attenuator with PIN diode switches has been made for controlling the noise temperature of the radiometer's reference noise source [Nakano et al., 1999], [Nakano et al., 2000].

Nevertheless, for the microwave noise measurements, traditional radiometers are also needed. Then a total power radiometer whose inner temperature is stabilized has been made and the characteristics of the radiometer has been analyzed [Nakano et al., 2000], [Nakano et al., 2000].

A6. Optical Communication System Measurement

Time domain system measurement techniques for optical communication include optical sampling waveform measurement, Q-value monitoring, polarization-mode dispersion (PMD) measurement, and timing jitter measurement. The key issue of optical sampling is the high efficiency optical nonlinear material needed to realize the all-optical sampling process. High efficiency materials of periodically-poled $LiNbO_3$ (PPLN) [Nogiwa et al., 1999; Ishizuki et al., 2000; Kawanishi et al., 2001], semiconductor optical amplifiers for four-wave mixing [Shirane et al., 2000], and Si-APD's for two-photon absorption [Thomsen et al., 1999; K. Taira et al., 2001] have been reported. An optical waveform was successfully measured at over 100 Gbit/s using a PPLN waveguide with fiber-fiber conversion efficiency h, defined as P_{out} / (P_{sample} P_{sig}), of 1.7 x 10^{-2} W^{-1} when P_{sample} was +14 dBm. Here P_{out}, P_{sample}, and P_{sig} are the powers of output light, input sampling light, and input signal light, respectively [Kawanishi et al., 2001].

Optical Q-value monitoring is another time domain measurement method. Shake et al. reported the concept of Q-value monitoring based on optical sampling [Shake et al., 1998] and this technique was used to monitor >100 Gbit/s TDM signals [Shake et al., 2000] and signals influenced by chromatic dispersion [Shake et al., 2001].

In high-speed TDM optical transmission systems over 40 Gbit/s, polarization-mode dispersion (PMD) in the fiber degrades the pulse shape, so the measurement and compensation of PMD is attracting interest. The main approaches to PMD measurement/compensation are pre-compensation and post-compensation methods, in which the differential group delay (DGD) is compensated in the transmitters and receivers, respectively. The compensators in the transmitters include a variable polarization controller [Sunnerud et al., 2000]. The compensators in the receivers include a polarization controller followed by a fixed DGD section of polarization maintaining fiber [Roy et al., 1999; Noe et al., 1999; Penninckx and Lanne, 2000], a free-space polarization delay line [Heismann et al., 1998; Pua et al., 2000], and a highly-birefringent nonlinearly-chirped fiber Bragg grating [Pan et al., 2000]. Recently, new PMD measurement methods were proposed based on optical frequency domain reflectometry [Zou et al., 2001], and phase-sensitive sideband detection [Madsen, 2001]. Compensation methods of higher-order PMD were also shown with one-stage post compensation [Karlsson et al., 2001] and two-stage post compensation [Yu et al., 2000].

As for the timing jitter induced by cross-phase modulation in WDM systems, Kisaka et al. showed that this jitter can be suppressed by increasing the channnel spacing and optimizing the dispersion of each channel [2000].

Recent developments in frequency-domain measurement techniques for optical transmission focus on group-velocity dispersion (GVD) measurement. A new technique for in-service monitoring of the GVD was proposed by Takushima and Kikuchi [2001], in which the transmission signal light itself acts as the probe light and the GDV value at the operating wavelength can be obtained only from the received signal. GVD monitoring was demonstrated in a 10 Gbit/s optical transmission system.

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