T & F COMPARISONS VIA BROADCASTING SATELLITE AND NAVIGATION TECHNOLOGY SATELLITE

Y. Saburi, Y. Yasuda, S. Kobayashi and T. Sato

Radio Research Laboratoires
Koganei, Tokyo 184, Japan

ABSTRACT

The paper describes the results of a preliminary experiment of T/F dissemination via the Medium-Scale Broadcasting Satellite for Experimental Purposes (BSE) and those of the international time transfer experiment via the Navigation Technology Satellite (NTS-1).

(1) The preliminary T/F dissemination experiments have been made using the BSE, which has the down-link of 12 GHz and the up-link of 14 GHz. The measured short-term stability of the received TV sub-carrier frequency is as good as in the terrestrial TV broadcasting, e.g., σ_y (10 sec)=3×10^{-11}. In order to establish the technique of the doppler shift canceling, the phase control servo including the satellite link, the pre-compensating frequency control using the measured values or using the orbital data of the satellite are tested. The amount of the residual doppler shift at the control station can be reduced to the order of 1 part in 10^{12} or less by use of the first and the second methods. The method using the orbit data is expected to give a control capability of a few parts in 10^{11}. Thus, the maximum value of the doppler shift at the farther-most place of the country is estimated to be $\pm2 \times 10^{-10}$ without any correction. As to the time comparison, the experiment is now proceeding.

(2) The experiment of the international time comparison via the NTS-1 had been made for about one year since October 1978, by the support of the GSFC of NASA and the NRL. The data of time difference between UTC(USNO) and UTC(RRL) are in good agreement with those via the portable clock of the USNO. By applying the correction for ionospheric delay using the model developed by Bent, the standard deviation of the data can be reduced to about one-half.

1. T/F dissemination via broadcasting satellite

The sub-carrier frequency and the synchronizing pulses in the terrestrial TV broadcasting have been widely used for precise T/F comparisons for more than ten years. But the change of the delay time has been occasionally observed in the time comparison between two places remotely located from each other, because of the changes of the relay route, the repeater and the transmitter characteristics and others. This difficulty will be removed by use of a broadcasting geostationary satellite,because uniform high accuracy in the time comparison can be expected all over the service area, if the variation of the propagation time mostly due to that of satellite position around the geostationary orbit—Doppler effect-can be precisely estimated and controlled [1].

Plan of T/F dissemination via BSE

The Medium-Scale Broadcasting Satellite for Experimental Purpose (BSE) was launched in April, 1978 to obtain the technical data necessary for establishing the future operational domestic satellite broadcasting system. The data of BSE spacecraft and the link budget (typical measured values) are given in Tables 1 and 2, respectively [2]. The satellite antenna has a suitable radiation pattern for providing high quality color TV broadcasting services to the whole Japan territory. Fig. 1 shows the BSE antenna radiation pattern (see Table 2) and places relevant to the plan of T/F dissemination. The value of 41.2 dB of the SN ratio in Table 2 corresponds to the TV picture quality of "Grade 4 (Good)" in the "5-grade assessment", which has been confirmed by the field tests with the receiving antenna of 1.6 m in diameter and a simple frequency converter (12 GHz to UHF). The tests with the receiving antennas of 0.75m and 1m in diameter have been made, too, showing the values of the "Grade" between "3 (Fair)" and "4", which correspond to comparativly high values of field intensity (approximately between 45 and 60 dB, 0 dB=1 μV/m) in the terrestrial TV broadcasting. Thus the T/F comparison can be made by just adding the small size receiving antenna, whose diameter is 1 meter or less,and the simple frequency converter to the apparatus for the comparison via the terrestrial broadcasting.

To establish the technique of controlling the doppler effect and then to evaluate the accuracy of T/F dissemination, a countrywide experiment using BSE is planing to be made in 1980. At the RRL Headquarters in Koganei, the received sub-carrier and the pulse are measured with respect to the RRL master clock. The measured difference in time and frequency is the amount of control to be applied to the TV signals being transmitted from the transmitting station at Kashima to the BSE satellite. Thus the time as well as frequency of the subcarrier and synchronizing pulses are made synchronized with the UTC(RRL) as received in Koganei and its vicinity.

A transportable receiving station and a few simple receiving stations remotely located from Tokyo area are supposed to make the frequency/time measurement of the received subcarrier and synchronizing pulses with respect to their own cesium clocks.

Besides, a time transfer experiment has been planned, where displays of the standard time will be obtained by use of the time code inserted in the vertical blanking intervals of the TV signals.

Results of preliminary experiment

(a) Frequency stability as received: The short-term frequency stability of the received color subcarrier from the BSE is given in Fig. 2. The measurement was made on the output signal of 3.58 MHz from the TV synchronizing generator with the composite video signal from the simple receiving system with an antenna of 1 meter in diameter. As seen in the Figure, the values of $3 \sim 4 \times 10^{-11}$ and about 4×10^{-12} are obtained for the averaging times of 10 and 100 sec. respectively, which enables general users to make precise frequency calibration in a short time. The values of $\sigma_y(\tau)$ are a little better than those in a terrestrial TV broadcasting, the field strength of which is as high as 70 dB, which fact can be well understood from the foregoing discussion on the TV signal quality.

(b) Doppler shift; In order to enable the frequency calibration to be very accurate, it is essential to minimize the doppler shift. So the measurement of the doppler shift of the received color subcarrier from BSE was made at Koganei, using rubidium and cesium standards at Kashima and Koganei, respectively, which were synchronized in frequency to 1×10^{-12} via terrestrial TV signals.

An example of results of the measurement is shown in Fig. 3. Curve a gives measured doppler values at Koganei (dots), together with calculated ones at Kashima (solid line), by use of the predicted values of the satellite orbit. The doppler shift amounts to about $\pm 1 \times 10^{-8}$ before the maneuver and decreases to $\pm 2 \times 10^{-9}$ after it. The curves b and c show respectively the values of doppler shift, relative to the value at Kashima, at Wakkanai and Okinawa, the farther-most locations in the country (Fig. 1). These two curves show the amounts of variation of $\pm 2 \times 10^{-10}$, which means that it is possible to distribute standard frequency with the accuracy better than $\pm 2 \times 10^{-10}$ everywhere in the country without any correction if the transmitted frequency is controlled so as to cancel the doppler shift as received in Tokyo area.

In order to cancel the doppler shift, the following three methods were tested:

(1) phase control servo including the satellite link,

(2) pre-compensating frequency control using the measured values,

(3) pre-compensating frequency control using the orbital data.

Fig. 4 shows the block diagram of the experiments for these methods. In the first method, the phase-locked loop of the first order consists of the transmitter, the receiver, the BSE satellite and the VCXO. In the second and third methods, a calculator-controlled phase shifter pre-compensates the sub-carrier frequency to be transmitted by an amount of the estimated doppler shift using either the orbital data or the measured values. The phase recordings of the transmitted and the received sub-carrier are made on Recorder Nos. 1 and 2, respectively, with reference to the cesium frequency standard.

(c) Results of phase control servo; An example of the results on the first method are given in Fig. 5. As shown in Fig. 5 (a), the frequency departure of the transmitted sub-carrier, which is almost the same as the inverse of the satellite doppler shift, showed abnormally large values of about $\pm 1 \times 10^{-8}$, because the routine maneuver could not be done at an appropriate opportunity by some reasons. In fact, the doppler shift was reduced to within $\pm 2 \times 10^{-9}$ by the maneuver made a few-days after that time. Fig. 5 (b) shows the doppler shift measured at Koganei in the same period of Fig. 5 (a) when the phase-locked loop was closed at the Kashima transmitting station. The peak values are a few parts in 10^{11}, even in such an unfavorable condition of the satellite position control. The phase record of received sub-carrier with respect to the cesium standard at Kashima station in given in Fig. 5 (c), in addition to that of 100 kHz signal, which is coherent to the transmitted sub-carrier. The maximum value of the residual frequency error in this case can be estimated to be 2×10^{-13}, taking account of the maximum rate of frequency change of about 7×10^{-13}/sec. in Fig. 5 (a) and the round trip delay of about 0.3 sec. via the satellite. In so far as seen on the record of 3.58 MHz, no phase variations larger than 3 ns could be observed.

(d) Result of pre-compensating control using measured values; The frequency measurements of the received sub-carrier are made at the transmitting station every 100 seconds. The fittings of polynominal of the second-order are made successively, each time using the past 20 data. The extrapolated value followed by the last measurement is used as the mean offset frequency to be transmitted for the next 100 seconds. The plot of Fig. 6 (a) shows the frequency departure of the transmitted frequency for 18 hours. Fig. 6 (b) shows the difference between the measured and the predicted values, of which standard deviation and mean value are 4.6×10^{-12} and -4.7×10^{-14}, respectively. The value of standard deviation is almost the same as that of short term stability of $\sigma_y(100 \text{ sec.}) = 4 \times 10^{-12}$ shown in Fig. 2, which means that the precision of the prediction in frequency is nearly limited by the short-term instability of the received signals. Fig. 6 (c) shows an example of the phase records of the received sub-carrier frequency and the transmitted frequency with respect to the Cs standard. The very small ripple on the record of 3.58 MHz is due to the difference between the mean offset values and the instantaneous doppler frequency change, and this can be easily reduced, if necessary, by shortening the offset period. The small amounts of drift and variation may be the integrated phase errors due to the frequency instability of received signal and the predicted value.

(e) Pre-compensating frequency control using orbital data; To make certain the accuracy of prediction of the doppler shift in the third method using the orbital data of the BSE, the frequency comparison was made between the sub-carrier received at Koganei and the computer-controlled sub-carrier which is offsetted by the predicted doppler shift obtained from the orbit calculation taking account of the solar light pressure. The observed difference was within $\pm 3 \times 10^{-11}$ for the period of one day.

2. International time comparison via NTS-1

The time comparison experiment via NTS-1 has been made at the RRL for about one year since October, 1978. The measurements were made with respect to UTC(RRL) by use of Time Transfer Receiver developed by the NASA. The weekly and final values of the time difference between the USNO and the RRL, UTC(USNO)-UTC(RRL), were calculated by the NRL.

The precision and accuracy of the result was almost the same as those reported at the past PTTI meetings by the NRL and other institutes. It is thought, however, that a fairly large effect of the ionospheric delay may be included in the data, because the measurements for this period were made only at the carrier frequency of 335 MHz. As it is difficult to know the actual total electron content at the time of every measurement, the corrections of the ionospheric delay to the measurements both at the NRL and the RRL is examined using the first-order algorithm [4].

In this algorithm, the average monthly diurnal change of time delay at any location, as a function of local time of day, has been represented by a simple positive cosine wave dependence for day time, with an additional constant term for night time. The amplitude, phase and period of cosine model and the constant term are the functions of geomagnetic latitude, season and solar activity.

An example of application of this algorithm is shown in Fig. 7 for 4 months from January to April, 1979. Fig. 7 (a) shows the final data calculated by the NRL, of which standard diviation from the fitting line is 0.53 μs. Fig. 7 (b) shows the corrected data for ionospheric time delay calculated by the algorithm, of which standard deviation is 0.34 μs. Thus fairly good improvement of the result was made in precision, and also in accuracy with respect to the USNO portable clock data.

Conclusion

The preliminary experiments mainly for precision frequency distribution via the BSE satellite were made and some techniques of the doppler shift compensating methods were studied. The results showed that the doppler shift at one point can be canceled to the order of 10^{-12}. The experiments for time dissemination is now being planned to be held in 1980.

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Table 1 BSE Spacecraft Summary

1.	Satellite location	110°E (±0.1°) on geostationary orbit
2.	Life	3 years
3.	Physical configuration	Rectangular solid (box type) with deployable solar array panel) Width 1.3 m Height 3.1 m Length 9.0 m (including deployed solar array panel)
4.	Weight	350 kg (at the beginning of life on geostationary orbit)
5.	Electrical power source of solar panel	780 W (at the end of life)
6.	Size of solar array panel	1.5m x 3m (two sheets)
7.	Attitude stabilization	Zero-momentum 3-axis stabilization using three momentum wheels
8.	Communications	
	Frequency	Receiving (up link) : 14 GHz Transmitting (down link) : 12 GHz
	Capacity	Two FM color TV channels (Bandwidth : 25 MHz each)
	Output power	100 watts/channel

Table 2 BSE Link budget

Up-link (Main Station)				
Main Station E.I.R.P.	(dBm/ch)		112.2	
Free Space loss	(dB)		-207.4	
Rx. antenna gain	(dB)		38.1	
Noise Power	(dBm/25 MHz)		-92.9	
Up-link C/N	(dB)		35.8	
Down-link Service area		Main station	Mainland	Remote islands
Antenna of Rx.	(m)	13.0	1.6	4.5
Tx. power	(dBm/ch)		50.0	
Tx. feeder loss	(dB)		-1.7	
Tx. antenna gain	(dB)	37.6	37.0	28.0
Free space loss	(dB)	-205.9	-205.8	-205.4
Rx. antenna gain	(dB)	61.9	43.0	53.5
Rcved carrier power	(dBm)	-58.1	-77.5	-75.6
Noise power	(dBm/25 MHz)	-96.4	-97.3	-96.6
Down-link C/N	(dB)	38.3	19.8	21.0
Total C/N	(dB)	33.9	19.7	20.9
TV signal quality				
FM improvement factor	(dB)		18.6	
Emphasis improvement factor	(dB)		2.9	
Unweighted S/N	(dB)	55.4	41.2	42.4

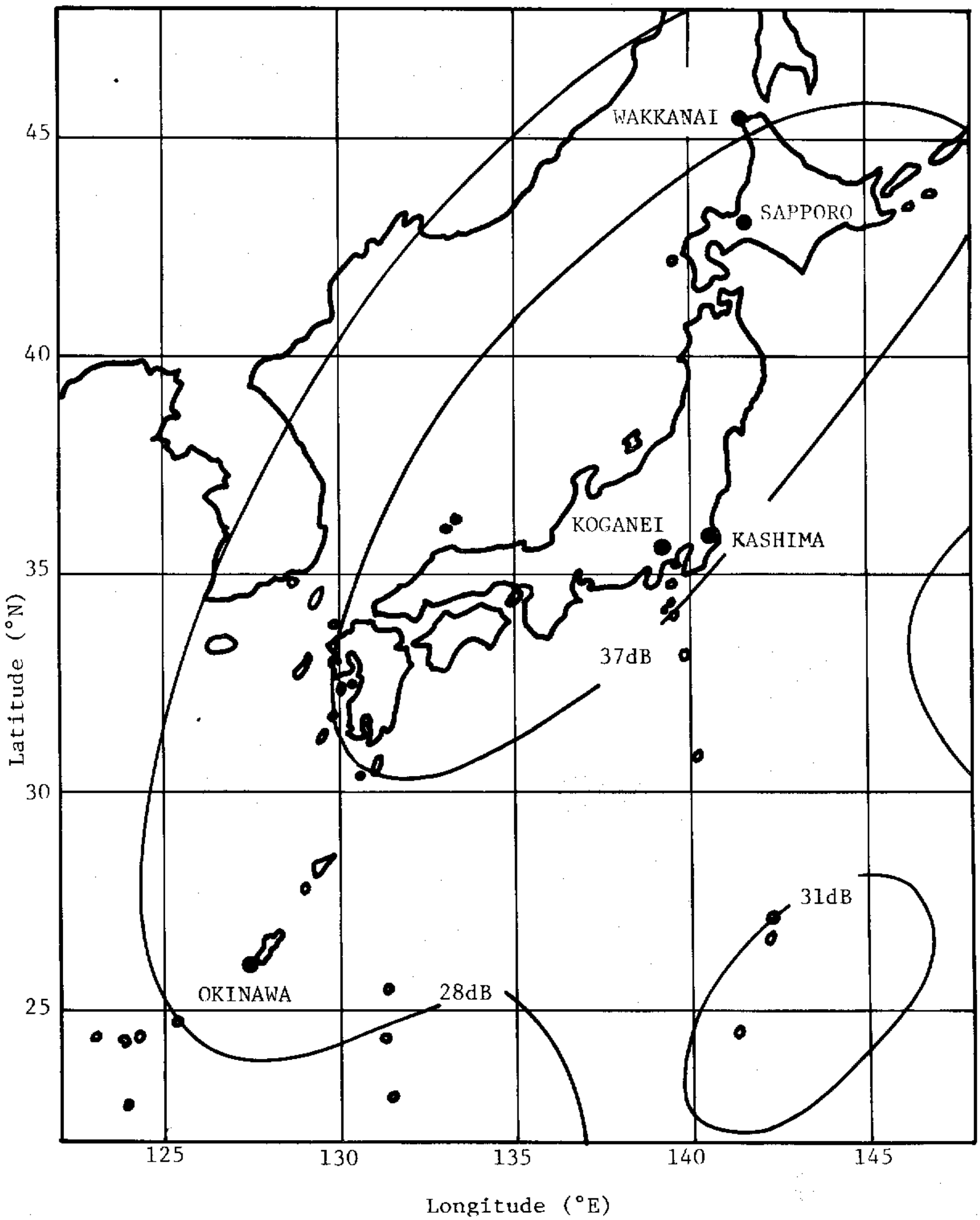


Fig. 1 BSE transmitting antenna pattern

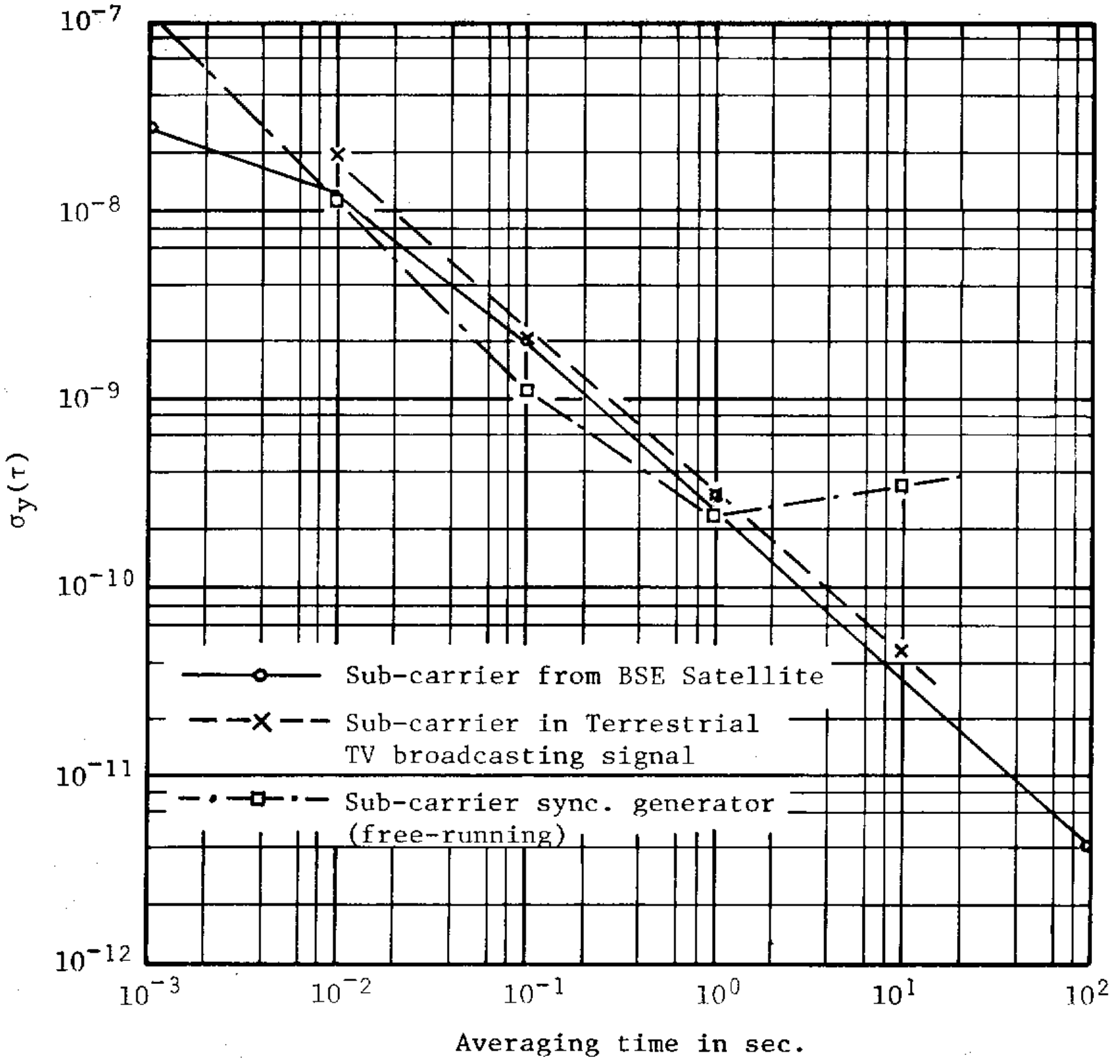
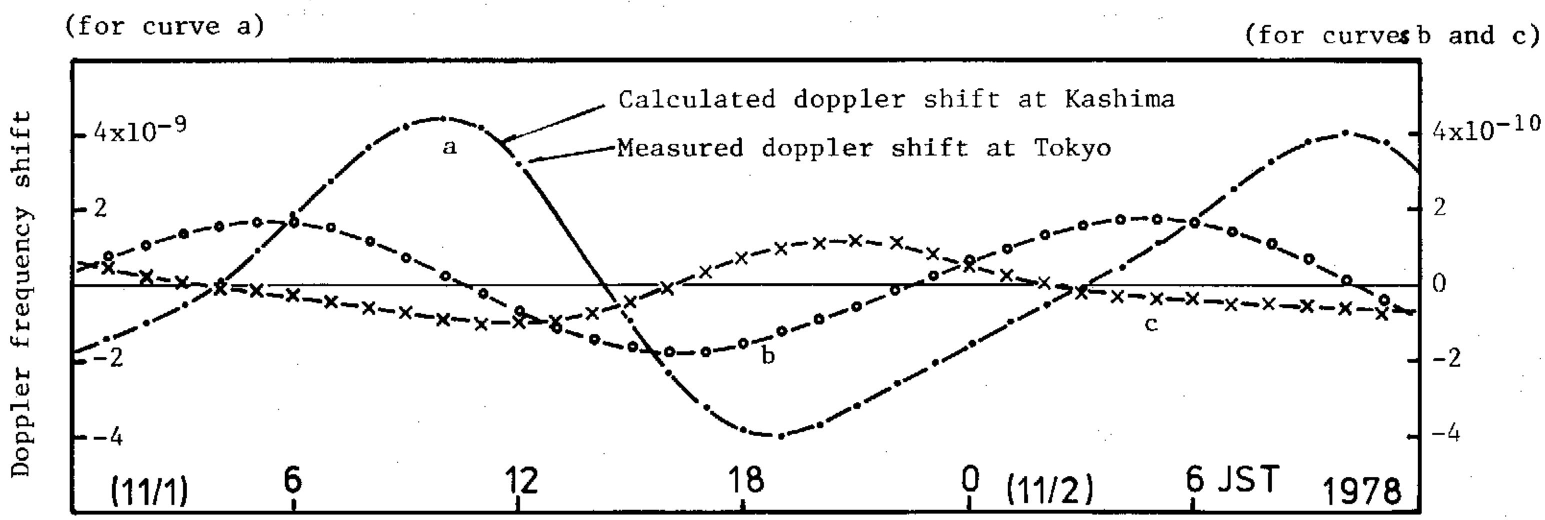


Fig. 2 Measured frequency stability



b: Calculated doppler shift at Wakkanai*

c: Calculated doppler shift at Okinawa*

*: Calculated frequency shift using orbit data, when compensated so as to cancel the doppler shift at the transmitting site.

Fig. 3 Doppler shift at Tokyo area and at the farther-most places in Japan

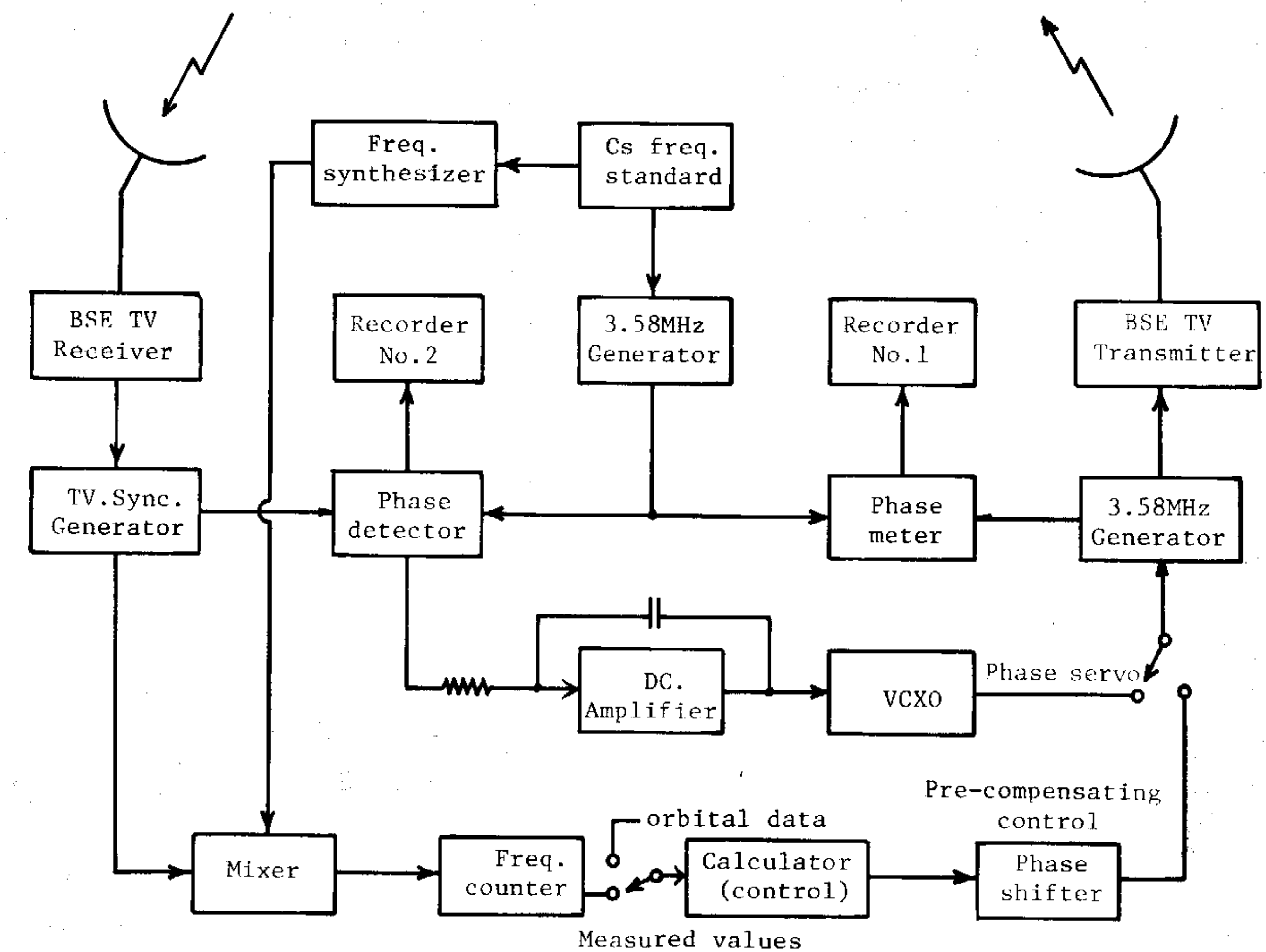


Fig. 4 Block diagram for doppler-shift canceling experiments

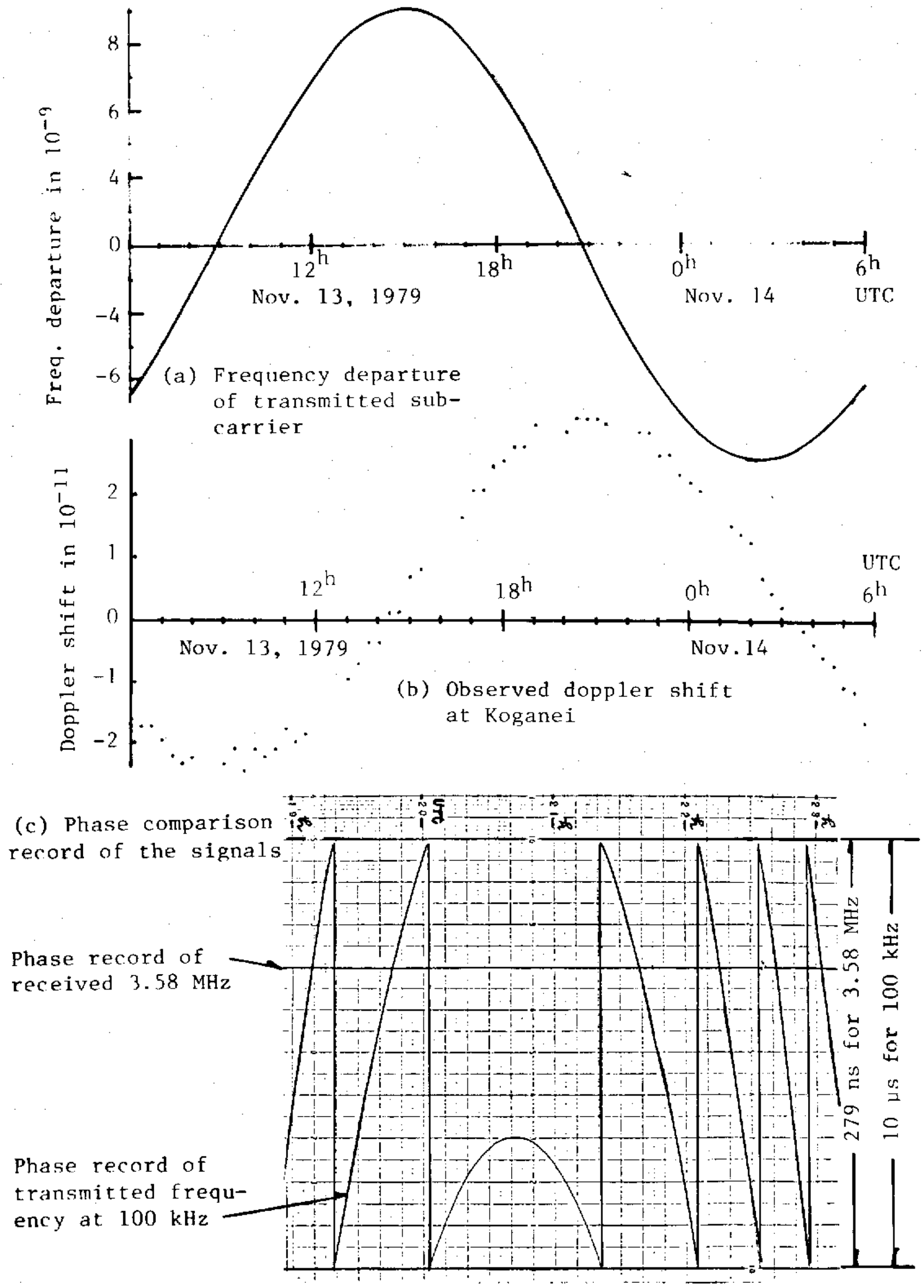


Figure 5. PLL–Controlled Data

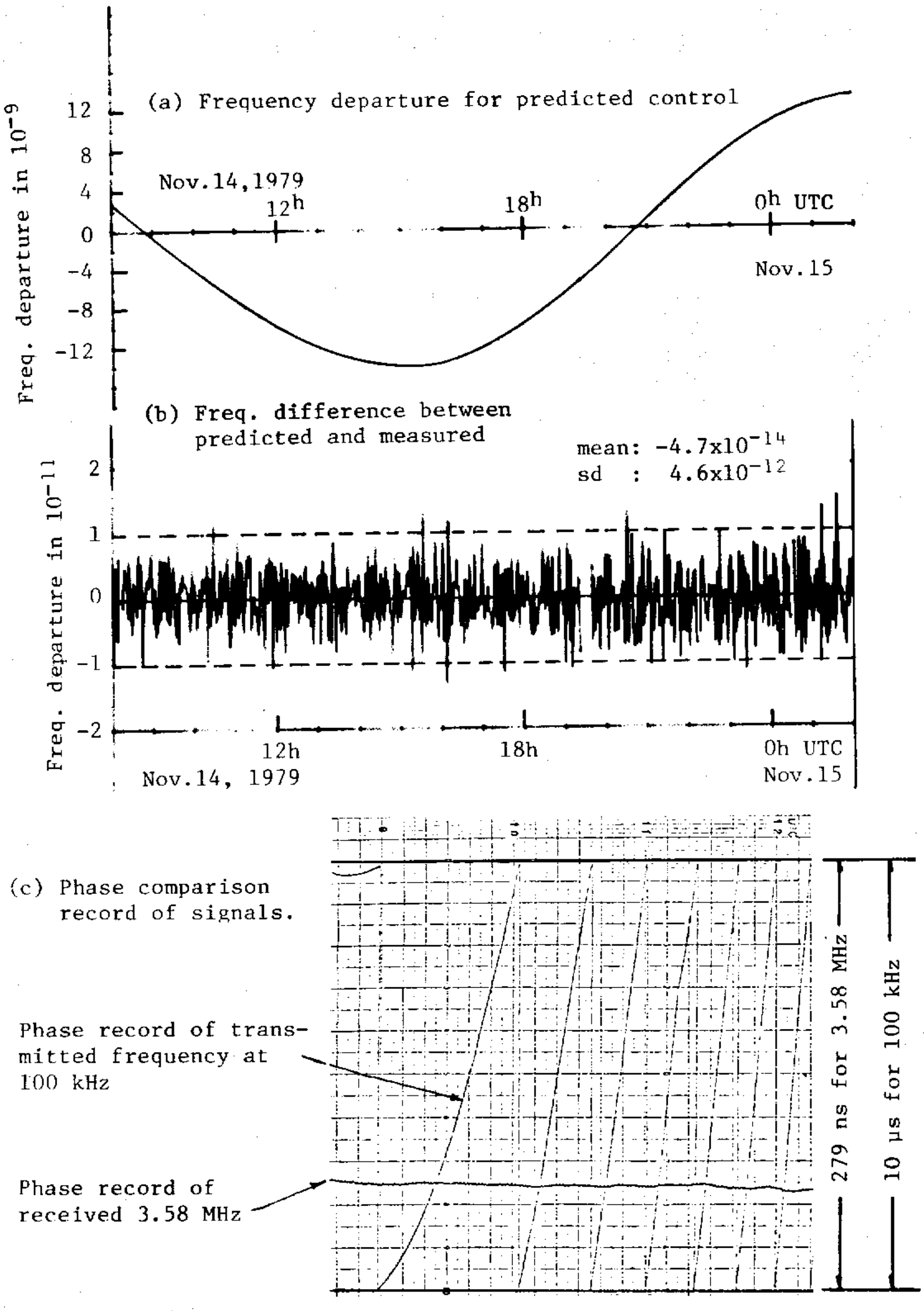


Figure 6. Pre-Compensating Control Using Measured Values

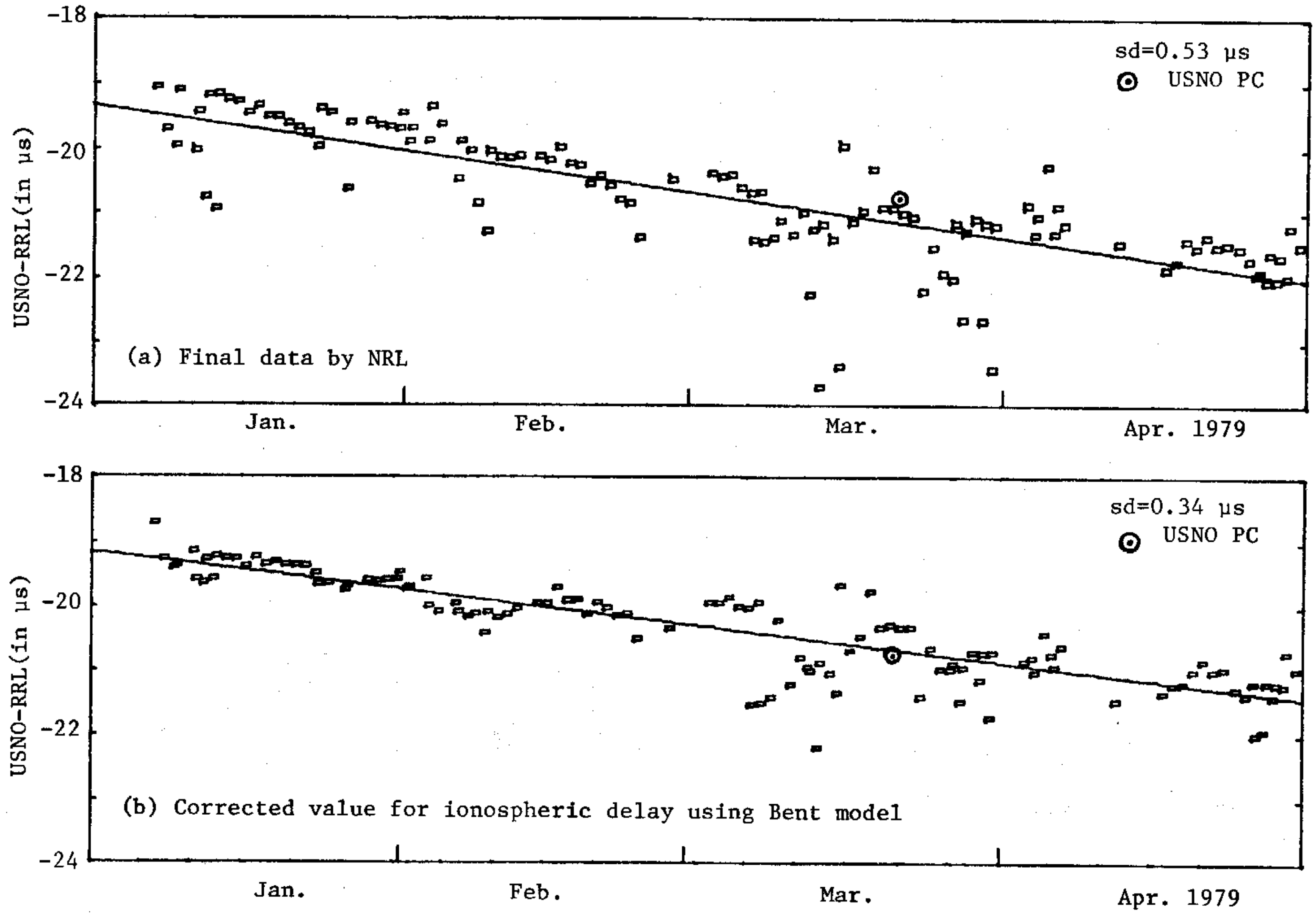


Fig. 7 UTC(USNO)-UTC(RRL) via NTS-1