

## FIRST EXPERIENCES WITH THE H-MASER EFOS 1

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### ABSTRACT

The H-Maser developed at ASULAB, S. A., Neuchâtel/Switzerland called EFOS 1 (Etalon Fréquence Oscilloquartz) has been moved from Neuchâtel to the Satellite Observation Station Wettzell, Federal Republic of Germany. The results are given on the performance measurements, on the dependence on external temperature and on external magnetic field, which are derived

at ASULAB by comparison with the H1-Maser. The experiences on the transportation of the H-Maser in operation are presented and the installation at Wettzell is described. The H-Maser-frequency is compared with the Caesium-oscillators of the station to derive the long term behavior.

## INTRODUCTION

The Institut für Angewandte Geodäsie acting within and on behalf of the Sonderforschungsbereich 78 (Satellitengeodäsie) is operating the satellite observation station Wettzell 400 km east of Frankfurt. The station Wettzell is equipped with a satellite laser ranging system, which will be extended to track the moon, and with satellite Doppler receivers. A radiotelescope for geodetic VLBI is under construction. A time and frequency system is available at the station to support the measurements with the required precise time- and frequency-information [Schlüter et al. 1981]. To achieve highest accuracy in the VLBI-measurements a H-maser will be used. The Swiss laboratory ASULAB/Oscillo-quartz offered to build a H-maser for these purposes; after that they decided to start the development of a commercial maser. The EFOS 1 Maser (Etalon Frequence Oscilloquartz) has been conceived in order to obtain optimum frequency stability for averaging times between 100 s and 10 000 s for the requirements in VLBI. Additionally the design goals are high reliability, easy maintenance and cost effectiveness. The design of the maser was described by Busca in [Busca et al., 1982].

After the factory acceptance test the maser was delivered to IfAG on July, 23 1982. The maser was transported to Wettzell in

full operation. The time and frequency system at the station in Wettzell consists now of 3 Cs-clocks, 4 Rb-clocks, 1 H-maser (EFOS 1) and 3 BVA-quartzcrystal oscillators. The constellation of the frequency generators at Wettzell does not allow to determine the maser frequency drift on the basis of measurements over a period of 3 month. This paper describes the results of the acceptance test performed at the laboratory of ASULAB using their maser H1 and the first experiences at Wettzell station.

#### MASER PERFORMANCE DERIVED DURING THE ACCEPTANCE TEST AT ASULAB

The acceptance test of the H-maser EFOS 1 has been performed in the period from 19<sup>th</sup> to 22<sup>nd</sup> July 1982 at the laboratory of ASULAB. The test procedure includes

- the thermal sensitivity
- the magnetic sensitivity
- the frequency stability (1s, 10s, 100s, 1000s)

The conditions for the test procedures were not the best: A few hours before starting the acceptance test it was necessary to replace the high voltage ion pumps power supply which required interruption of about 3 hours of the masers normal operation. Later during frequency stability test a main power failure occurred (thunderstorm) which caused a complete interruption of the reference maser H1 and the air conditioning system.

It is clear best performance results could not be achieved under such conditions. In the following the test results are presented and also those results are given which have been determined from measurements preceding the acceptance test.

a) thermal sensitivity

The temperature was changed stepwise (from 22.8 °C to 18.8 °C) and the corresponding frequency shift was measured by comparison with the frequency of the reference maser H1 , which was kept at a constant temperature. The thermal sensitivity was obtained as

$$\Delta f/f = +1.7 \times 10^{-13} / \text{degree Kelvin.}$$

As the thermal test were performed only some hours after the high voltage power supplies replacement, the frequency of EFOS 1 was not stabilized enough and the detected frequency change was not only caused by the temperature change. These data do not correspond to the measurements preceding the acceptance test, made under stable conditions which give a thermal sensitivity of

$$\Delta f/f = -2 \times 10^{-14} / \text{degree Kelvin.}$$

b) magnetic sensitivity

Two thin square coils were used to simulate variations of the vertical components of the ambient magnetic field. The maser frequency (EFOS 1) was measured by comparison with the frequency of the undisturbed second maser H1 in the following sequence. The ambient field increment was changed twice from + 500 mGauss to - 500 mGauss without frequency measurement to eliminate the possibility of transient hysteresis effects. After that 5 cycles of frequency measurements (100 s) have been performed by an ambient field of + 500 mGauss resp. - 500 mGauss and by a C-field of 415 microGauss. The sensitivity was obtained as

$$\Delta f/f = -1.4 \times 10^{-13} / \text{Gauss}$$

### c) Stability Test

Obviously under the given environmental conditions the frequency stability test results can not be as good as under stable conditions.

The Allan Variances derived under the test conditions are given in table 1 compared to the results obtained under stable con-

$\tau$ in s	test conditions		stable conditions	
	$\sigma(\tau)$	number of samples	$\sigma(\tau)$	number of samples
1	$4.1 \times 10^{-13}$	100	$1.5 \times 10^{-13}$	100
10	$6.7 \times 10^{-14}$	100	$1.9 \times 10^{-14}$	100
100	$7.7 \times 10^{-15}$	100	$6.5 \times 10^{-15}$	100
1000	$3.5 \times 10^{-15}$	63	$1.7 \times 10^{-15}$	100
10000	-	-	$2.6 \times 10^{-15}$	18

Table 1, frequency stability of EFOS 1 derived during the acceptance test and derived under stable conditions.

ditions. The measurement system bandwidth was 1 Hz for the test conditions and 6 Hz for the previous measurements. Consequently the 1 s and 10 s values measured under stable conditions have been normalised to 1 Hz bandwidth. The frequency stability measurement system has been described in [Busca et al., 1982].

## TRANSPORTATION FROM ASULAB/NEUCHATEL TO WETTZELL

The H-maser was transported from Neuchâtel to Wettzell in full operation without interruption (figure 1). The transportation took arround 24 hours with 10 hours driving on a distance of about 650 km. 1 Stop during night time was neccessary, which was used to charge the batteries.

## INSTALLATION AT WETTZELL

The maser was installed in a small cellar room of about  $2.5 \text{ m}^2$ , which is thermally isolated (cold thermostat). The maser was put on a sand-filled trough in which a granit plate is "swimming" to protect the maser against vibrations transferred by the ground. The complete trough stands on a 2 cm thick rubber plate (figure 2).

After the transportation and the installation of the maser, low current degaussing was needed.

The temperature in the maser room climed up to  $27^\circ \text{ C}$  in July and August mainly caused by the hot summertime we had in Europe. Now the temperature is  $25^\circ \text{ C}$ . The room is isolated in such a manner that no daily temperature variations were observed.

## MASER FREQUENCY CHANGE DUE TO TRANSPORTATION

Before the acceptance test the maser cavity was tuned by spin-exchange technique using the maser H1 as a reference. The tuning was done for two different values of the "C" field

(namely 83  $\mu$  Oersted and 415  $\mu$  Oersted). The results show that the cavity tuning setting was independent of the "C" field within the error of  $1 \times 10^{-14}$ . The nominal "C" field value was set and the synthesizer frequency was adjusted to the value required for compensating the evaluated Wall shift ( $-2 \times 10^{-11}$ ) and the second order Doppler shift ( $-4.3 \times 10^{-11}$ ). The maser frequency was compared with a commercial Cs-standard and a relative frequency off-set of  $4.5 \times 10^{-13}$  was found. After the installation at Wettzell the maser frequency was compared with the 2 Cesium standards and a frequency off-set of  $<1 \times 10^{-12}$  was measured. This imply that no major changes of the maser frequency occurred during the transportation.

#### THREE MONTHS EXPERIENCES AT WETTZELL

The maser frequency was controlled against the frequencies generated by the Cs-Standards over a period of about 80 days. Phase measurements of the 5 MHz signal of the maser against the 5 MHz output of the Cs-standards have been carried out with a HP-5370 A counter. To eliminate the noise of the Cs-standards a mean value was determinated by measuring of  $10 \times 100\,000$  samples of the time elapsed between the zero point crossings of the EFOS-frequency and Cs-standards-frequency. The precision of the mean phase measurement is better than 0.1 ns. The results of the measurements are plotted in figure 3. The measurements were performed against the two Cs-clocks (CS 7/Ser. No. 131 and CS 8/Ser. No. 173). Curve I shows the LORAN C comparisons of the CS 7 (daily phase value correction is taken into account) and gives the frequency relation to UTC (USNO-MC). The second curve (II) shows the comparison of the two used Cs-standards and curve III and IV give the maser-frequency compared to the Cs-standards.

The first change in the slope appears in curve I, II and III and happened after the installation of a BVA-quartz oscillator next to the CS 7 frequency generator (Mod. Jul. date = 45 199). A correlation of both events, the BVA-installation and the slope change, can not be excluded.

A slight change occurs in the curve III and IV (on Modified Julian date = 45 214). The change is obviously caused by a change of the maser frequency, possibly due to thermal effects (figure 4).

The maser stopped its operation on Mod. Jul. date = 45 226 due to a power interruption at the station over three hours. Possibly the vacuum became to low and the maser stopped the oscillation. The correct vacuum was restored after 2 days elapsed. The follow on frequency comparisons indicates only a small difference against the frequency before the maser interruption ( $2 \times 10^{-13}$ ).

The last change of frequency in figure 3 appears on the curve II and IV on MJD = 45 255. The CS 8-standard was moved from the temperature uncontrolled laboratory room to a separate, isolated cellar (cold thermostat) which has been finished at that time.

The measurements plotted in figure 3 were fitted by a linear approximation. The slope was determined for the curve 2, 3 and 4 within  $< \pm 3\text{ns/d}$  and for the curve I within  $< \pm 10\text{ns/d}$ . The residuals are given in figure 5. The Allan Variance was estimated as

$$\sigma_{\text{EFOS-CS}} \sim 2.5 \times 10^{-13} \text{ (over 1 day).}$$

It is obvious, that this value is mainly influenced by the Cs-standard behavior. The Allan Variance estimated from the CS 7 against CS 8 measurements is

$$\sigma_{\text{CS } 7/\text{CS } 8} \text{ (1 day)} \sim 6 \times 10^{-13}.$$

Assuming the same quality for both Cs-standards the performance of the Cs-oscillators could be estimated as

$$\sigma_{\text{CS}} \text{ (1 day)} \sim 6 \sqrt{2} \times 10^{-13} \sim 4 \times 10^{-13}$$

It has to be pointed out, that the H-maser performance could not be estimated on the basis of the measurements over a 3 month period by the clock ensemble of Wettzell. From the given results it could be stated, that the 1 day behaviour of the maser is better than from the Cs-standards. To have results for more than  $\tau = 1$  day, longer undisturbed series of observations are needed. However no systematic frequency drift of the maser could be ascertained, which will show up as a parabolic curve in the figure 3. An upper limit of the maser frequency drift from the present data can be roughly estimated as  $< 1 \times 10^{-14}/\text{day}$ .

Studies on oscillator performance have been started by e.g. comparing the phase of the maser frequency against the Cs-clocks and the BVA quartz-oscillators. Currently no results are available. To demonstrate that good results will be expected the phases of a BVA oscillator and of a Cs-oscillator against EFOS are plotted in figure 6. The smooth curve is the phase of the BVA-crystal-oscillator. Full scale of each record is about 10 ns.

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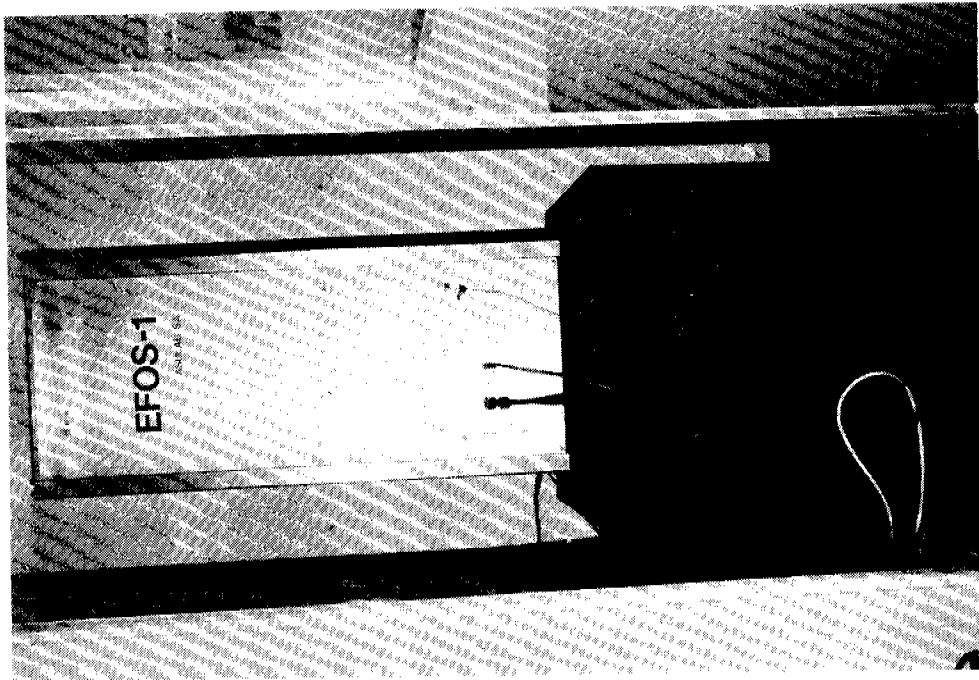
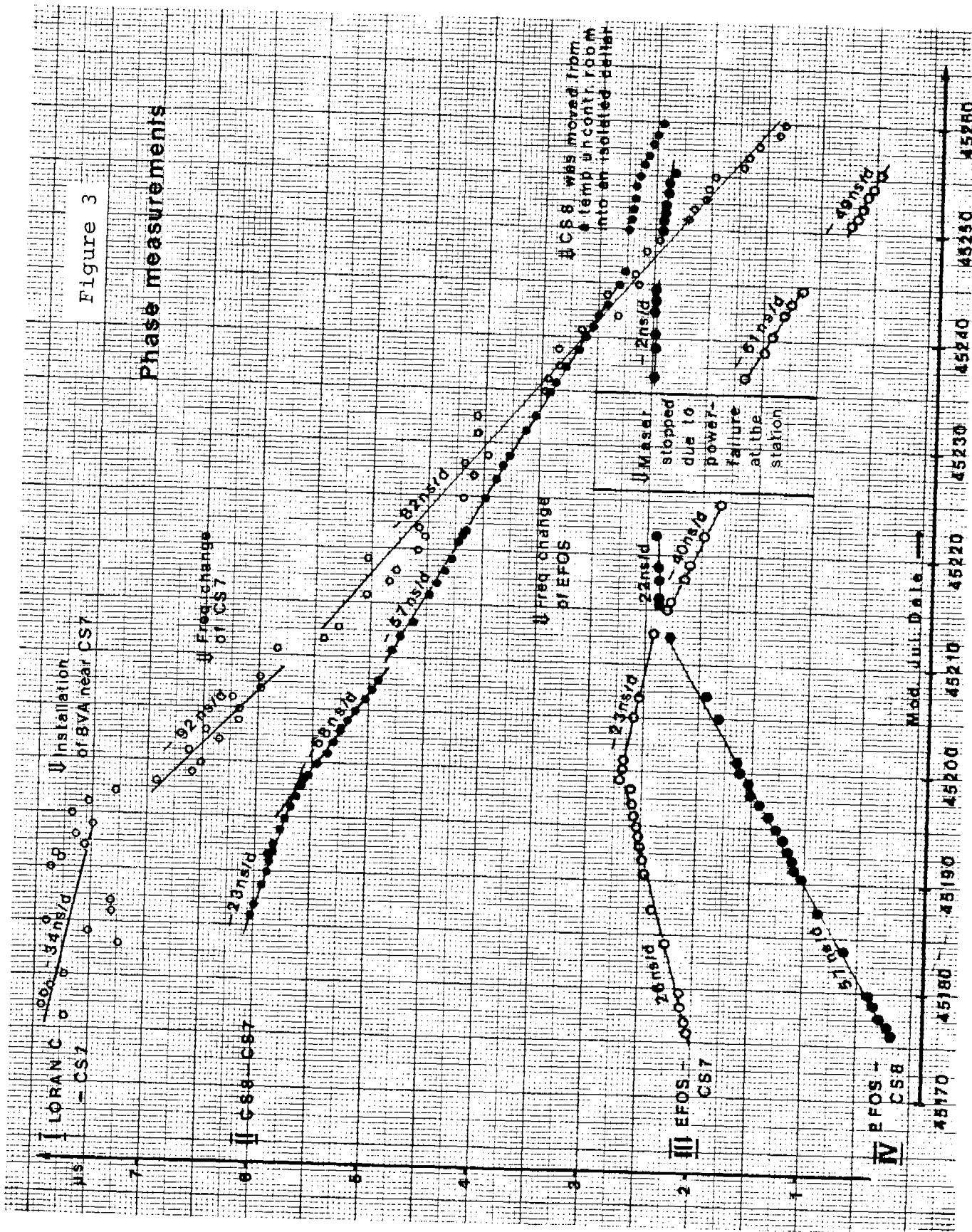


Figure 2 - Maser installed at  
Wettzell.



Figure 1 - Transportation of the  
Maser from Neuchâtel  
to Wettzell in operation.



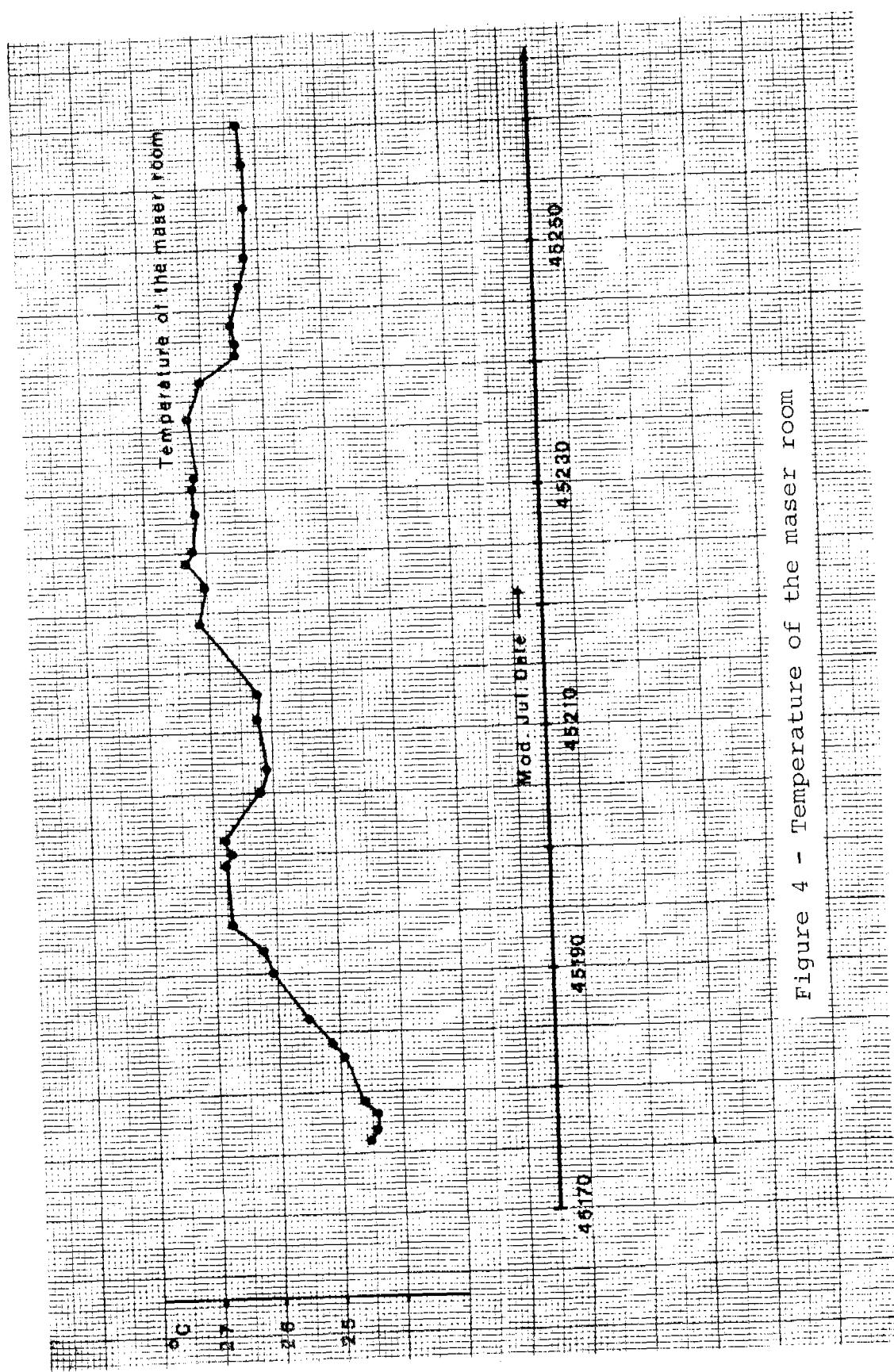
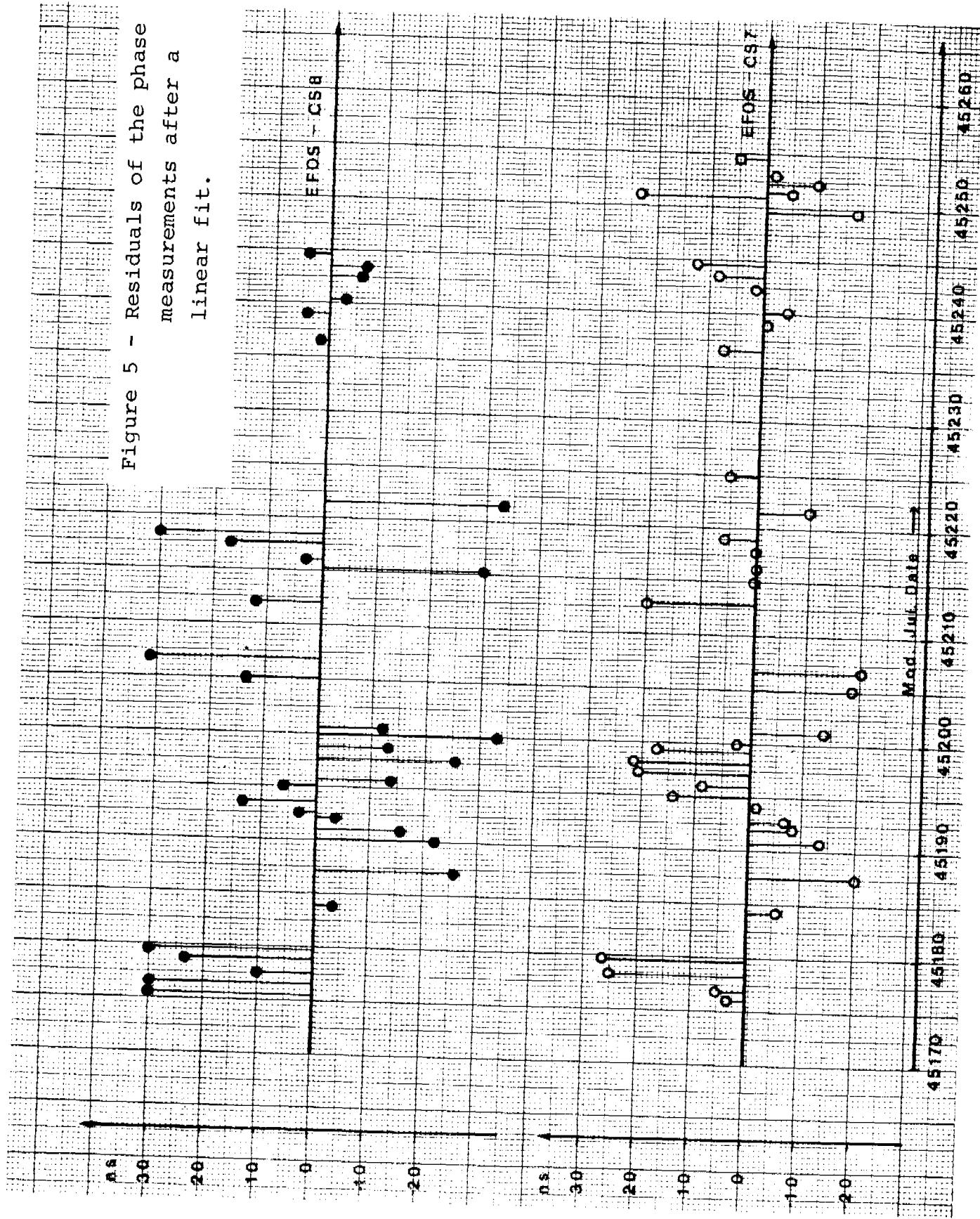


Figure 4 - Temperature of the maser room

Figure 5 - Residuals of the phase measurements after a linear fit.



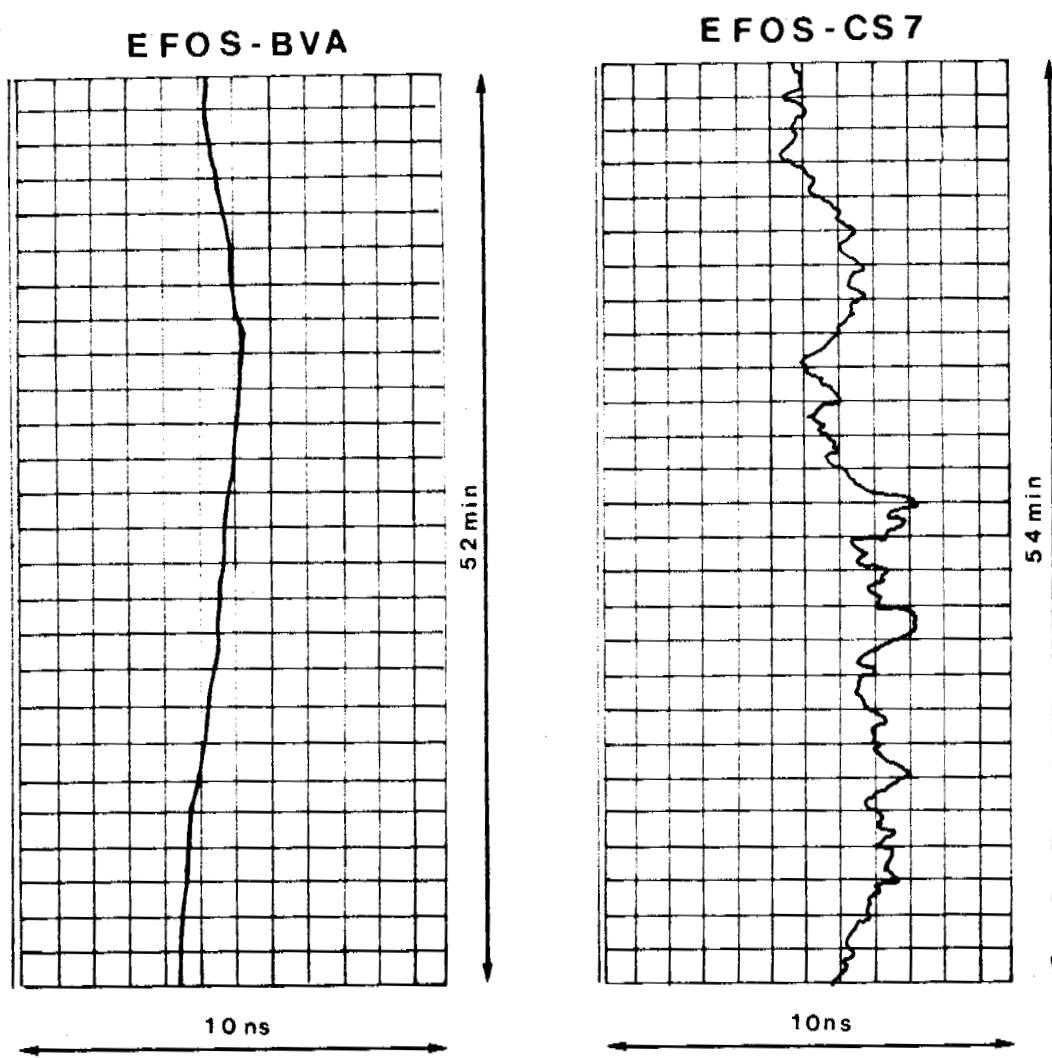


Figure 6 - Phase - comparisons of  
the BVA-quartz oscillators  
against EFOS, CS-oscillator  
against EFOS

QUESTIONS AND ANSWERS

DR. COATES:

Any questions?

MR. SAM WARD, Jet Propulsion Laboratory

I noticed that after the power failure, the drift term changed. Is there any explanation for that?

MR. BUSCA:

After the power failure, this is the drift we had before. This is after only a rate of twenty nanoseconds per day. I have no explanation, maybe it's due to thermal effects because the cellar room is not well insulated.

MR. LAUREN J. RUEGER, JHU/APL

Do you have a means to flux tune the masers after you are on the station site?

MR. BUSCA:

No.

DR. COATES:

Did everybody understand that? Your answer was "no", right?

MR. BUSCA:

Yes.