THE SHUTTLE EXPERIMENT NAVEX COMPLETED ON SPACELAB MISSION D1

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ABSTRACT

From Oct. 30 to Nov. 6 1985 the first dedicated German Shuttle Mission D1 with the Spacelab laboratory on board took place. One of the more than 70 experiments on board was the Navigation Experiment NAVEX. A Cs- and a Rb-clock onboard were used for the generation of PN-code navigation signals. During the experiment these clocks were compared with the ground master clock by one-way and two-way methods. In this paper a survey will be given on the progress of the experiment and on first raw data, which indicate already a satisfactory operation of the used spread spectrum technique and a very accurate confirmation of the predicted relativistic clock effects.

INTRODUCTION

The U.S. Space Shuttle Challenger was launched on Oct. 30 with the European Spacelab as a payload on board. The Spacelab contained more than 70 experiments which were controlled in detail from the German Satellite Operation Center at DFVLR *) near Munich. Here all experiments were aassembled. They observed and directed the activities of the astronauts in the Spacelab via voice link and TV.

Two of the experiments could not find a place inside of the Spacelab. They had to stay outside in the cargo bay mounted on a Unique Support Structure (USS) as shown in Fig. 1 and 2. One of these was the NAVigation EXperiment NAVEX, proposed and performed by DFVLR and by SEL **). The on-board equipment of this experiment was installed in three cylindrical containers: one of them contained the on-board time reference, consisting of a Cs and a Rb-frequency-standard with the appertaining electronic devices and with a battery as a back up power supply; the second housed a L-band transmitter with PSK-modulation and power amplifier and a C-band radar transponder; the third contained a L-band receiver assembly, a time interval measurement unit, a processor and a data acquisition and control system. The transmitting and receiving antennas were mounted on a special antenna support structure.

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*) DFVLR = Deutsche Forschungs- und Versuchsanstalt für Luft- und Raumfahrt

**) SEL = Standard Elektrik Lorenz, Stuttgart

The intention of the experiment NAVEX was to investigate techniques and methods for future time transfer and navigation systems using satellites.

OBJECTIVES AND EXPERIMENT CONFIGURATION

For a more detailed description of the experiment see [1, 2]. Ih this chapter only a general view shall be given on the main functions and facilities of NAVEX.

Fig. 3 illustrates the sequential steps and aimed objectives: beginning at the right side, at first the on-board time scale had to be compared with the ground master clock at DFVLR Oberpfaffenhofen by a two way L-band link. Simultaneous ranging with a C-band radar was provided for determination of the ionospheric propagation effects by the two frequency method and for the determination of the range between Shuttle and the ground control station with high accuracy.

In a further step by receiving the L-band Shuttle signals at two additional ground receiving stations in Stuttgart (SEL) and Braunschweig (PTB*) the Shuttle position should be determined by a modified one-way ranging method. In these measurements a third experimental receiving station participated partly, developed and operated by the University of Stuttgart. All ground stations were equipped with synchronized Cs-clocks. The accuracy of these one way measurements can be investigated by comparison with the more accurate two way measurements.

Finally when the Shuttle positions, the parameters of the onboard time scale and the ionospheric propagation effects are known, the one way positioning of a single ground receiving station can be tested by evaluating the measurements of two successive passes of the Shuttle.

In fig. 4 the overall experiment configuration is shown with the different ground stations mentioned above, with a frequency transfer link between the launch site and the control station in Oberpfaffenhofen and with a data communication link from the Shuttle via TDRS and U.S.A. to Oberpfaffenhofen. There the operations of the ground stations were coordinated, the housekeeping data of the onboard equipment were controlled and the experiment measurement data were checked and stored. These control tasks were supported by the German Satellite Operation Center (GSOC). The on board time interval measurement data were transmitted directly during each pass from the Shuttle to the ground control station Oberpfaffenhofen by a spread spectrum signal modulated on the L-band PN-coded time signal.

With this configuration and several additional test devices the experiment started on the 30th of October. The frequency transfer between the launch site and Oberpfaffenhofen was performed before and after the D1-mission by GPS satellites as tested in 1982 and described in [1]. The synchronization of the station clocks was performed by clock transportation and by additional GPS clock comparisons.

*) PTB = Physikalisch-Technische Bundesanstalt in Braunschweig

PROCEDURES DURING D1 MISSION

The launch at 17:00 UT took place exactly on schedule and the orbit of the Shuttle differed only slightly from the nominal one. Only once during the whole mission a change of the NAVEX subtimeline had to be performed according to a lag of Challenger of 2 minutes after 4 days.

12 hours after launch the onboard clocks were switched on and 6 hours later the clocks were adjusted to UT. During the following passes unexpected time lags were measured at all ground stations, which changed from pass to pass, according to an unwanted repetition of the NAVEX clock adjustment. After analyzing this effect, the undesired signal could be removed with the support of Marshall Space Flight Center and with the help of the Spacelab crew.

After this episode the experiment run as planned: at all passes the equipment worked well, minor interruptions occured only near zenith and at low elevation angles $\varepsilon < 5^{\circ}$. In the meantime between two passes the raw data from all ground stations were transferred to the control center and checked with respect to estimated values. During an undisturbed measurement interval of more than 74 hours a time lag of the onboard Cs-clock of 87,07 µsec was observed relative to the behaviour of the same clock on the ground. Finally 146 hours after launch the onboard equipment was switched off by ground command.

FIRST RESULTS

The behaviour of the onboard Cs-clock on the ground and in the orbit relativ to the master clock in Oberpfaffenhofen is shown in fig. 5. The difference between the two curves agrees with the predicted relativistic effect better than 1%.

Both the predicted values as well as the measurement values will have to be corrected slightly as soon as the definit orbit of the Shuttle is known and after the post mission control measurements of the clocks will have been completed.

Although the measured values in fig. 5 are only unsmoothed single sample values near the culmination of each pass, the deviations of the straight line curve are not visible at this scale. Therefore these deviations are added with an enlargement factor of 50. Fig. 6 shows raw data from a single pass measurement with fluctuations in the order of $\sigma \approx 5$ nsec.

Thus we expect that after smoothing and adding small ionospheric corrections the precision of clock comparisons will be clearly better than the aspired goal of $\sigma \lesssim 10$ nsec. For investigation of the accuracy of the experiment data some pending calibration measurements will have to be performed as soon as the onboard equipment will be transported back to Germany.

ACKNOWLEDGEMENT

Finally we would like to mention that this experiment was also a success in respect of good cooperation.

This is valid not only for the cooperation with many colleagues in DFVLR and SEL, our partner in the experiment, but also for all other establishments in Germany and in the United States which supported us:

BMFT	Bundesministerium für Forschung und Technologie, Bonn which initiated the mission D1 and gave fundings
DFVLR	German Satellite Operation Center, Oberpfaffenhofen where the activities during the mission were controlled and support to the ground segment was given
SEL	Standard-Elektrik Lorenz, Stuttgart developed and manufactured the NAVEX equipment
PTB	Physikalisch-Technische Bundesanstalt, Braunschweig provided NAVEX with atomic clocks for time and time transfer
ERNO	Entwicklungsring Nord, Bremen was responsible for all D1 integration activities
D1	Project Management and Operation Team of Spacelab mission D1 supported data transfer and experiment change requests
NASA	Kennedy Space Center supported final tests of the onboard equipment

Eastern Space and Missile Center; Range Engineering Systems provided a portable clock for the clock comparisons at KSC and made time measurements by clock transfer and GPS satellites.

Last not least the support from the Shuttle Crew and the encouraging and friendly advices of outstanding experts in this field as Dr. Winkler from USNO, Dr. Allan from NBS, Prof. Alley from the University of Maryland, and Prof. Vessot from the Smithsonian Institute have to be emphasized in this respect.

LITERATURE

[1] S. Starker, H. Nau, J. Hammesfahr, H. Tschiesche
NAVEX - A Space Shuttle Experiment with Atomic Clocks.
Proceedings of the 14th PTTI Applications and Planning Meeting 1982, pp. 181 - 201.

[2] J. Hammesfahr, H. Nau, S. Starker
A Space Shuttle Experiment for Future Time Transfer and Navigation Systems.
35th Congress of the International Astronautical Federation
Oct. 7 - 13 1984, Lausanne, Switzerland

[3] S. Starker
Spacelab Experiments with Atomic Clocks
ESA SP-137 Proceedings of European Workshop; 16 - 21 January 1978

[4] S. Starker, D. Rother
A Spacelab Experiment on Clock Synchronization and One-Way-Ranging
Ortung und Navigation, I/1979 Vierteljahresmitteilung der Deutschen Gesellschaft für Ortung und Navigation (DGON), pp. 35 - 53.

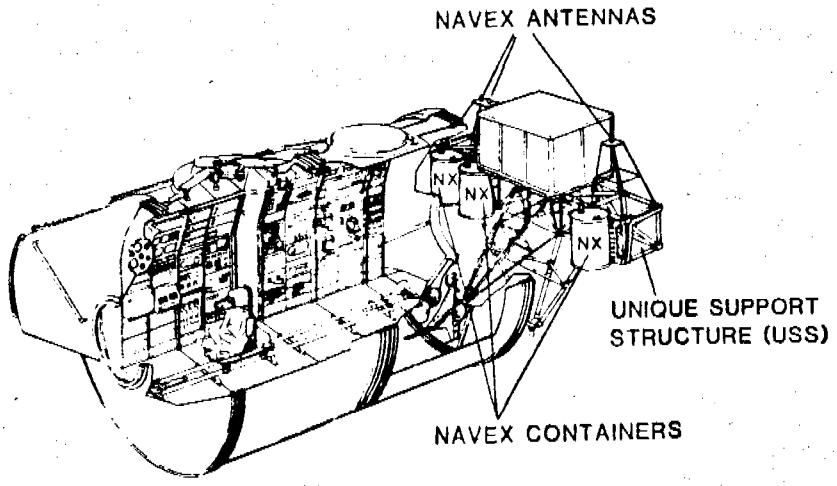

Fig. 1 - Accomodation of D1 on-board equipment

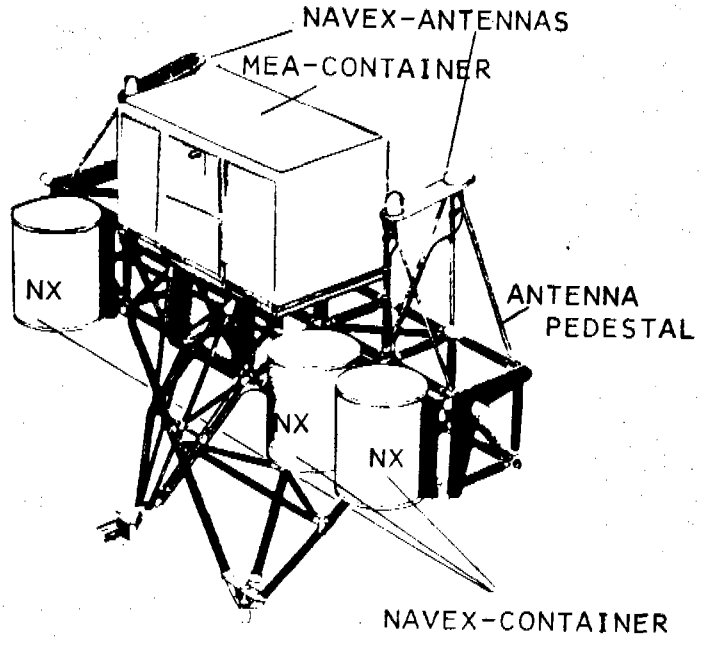

Fig. 2 - NAVEX onboard equipment in 3 GAS-containers mounted on a Unique Support Structure

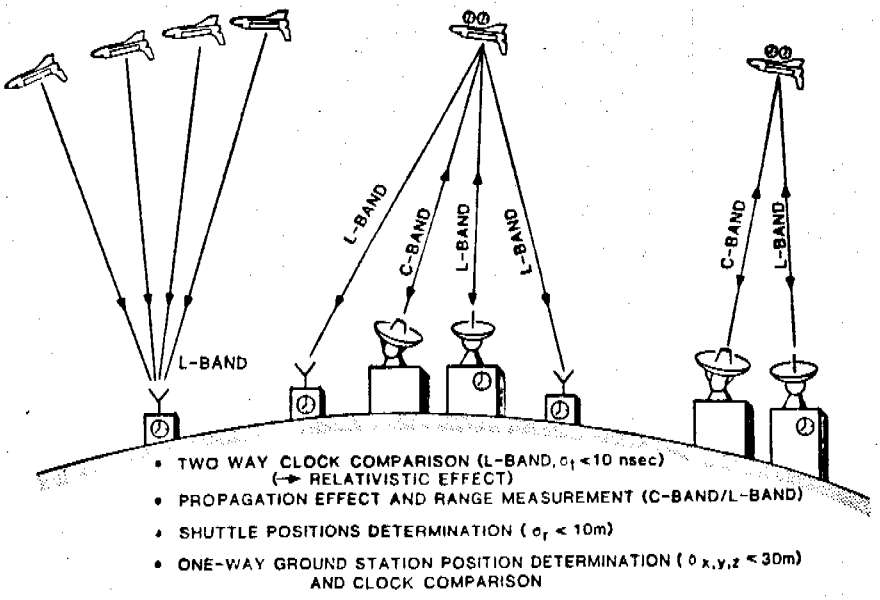

Fig. 3 - NAVEX - Objectives

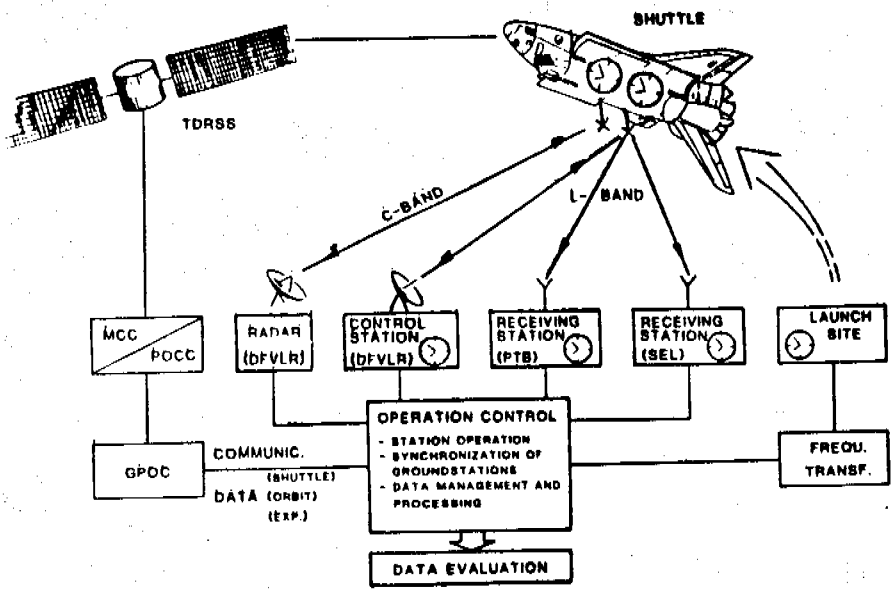

Fig. 4 - NAVEX - Experiment Configuration

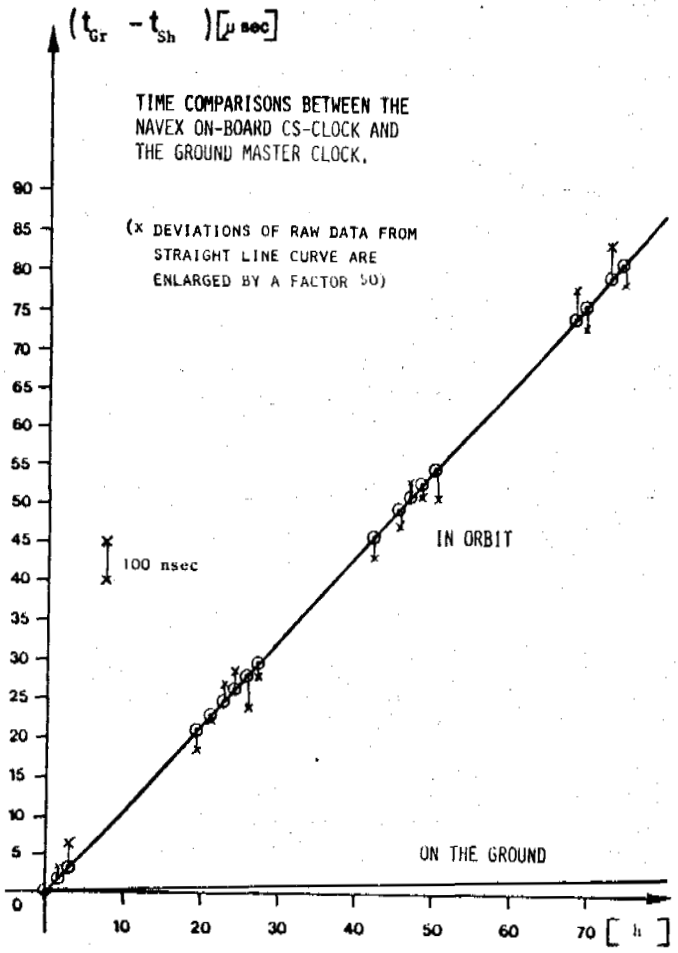

Fig. 5 - Measured time differences between the onboard Cs-clock and the ground master clock in the orbit and on the ground (a single sample from each pass).

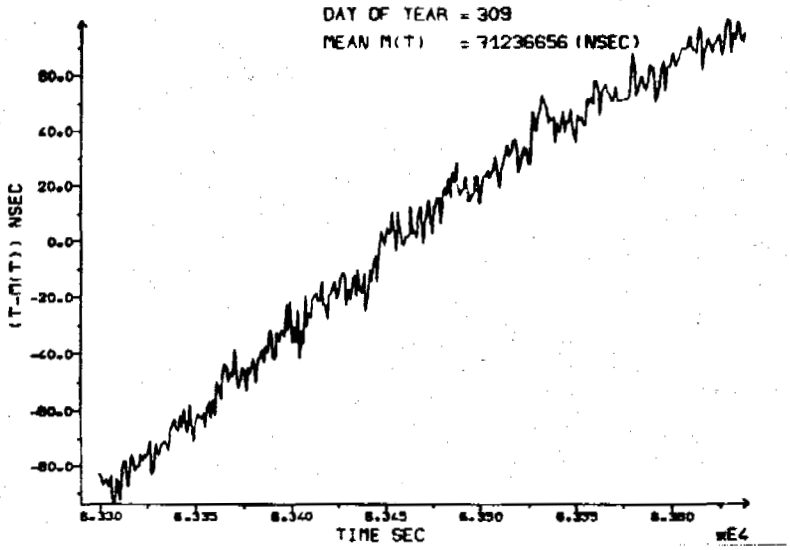

Fig. 6 - Raw data of measured time differences between the onboard Cs-clock and the ground master clock during one pass of the Space Shuttle.

QUESTIONS AND ANSWERS

UNIDENTIFIED QUESTIONER:
Do you have any information, even anecdotal, as to what may be the operating period of these devices? Say if one were made and left unattended somewhere.

MR.VESSOT:
This is for the conventional masers, I gather.

QUESTIONER:
For either the space borne or ground maser.

MR. VESSOT:
I think that the one of the best diagnostics is the frequency shift that could result from wall contamination. That is readily made by simply tuning the maser and looking at what the frequency is then compared to what it might have been earlier. This, of course requires a reference. The other thing is the question of background pressure and all the usual diagnostics of vacuum systems. Yet another one is the monitoring of the IF level, that is the signal level as produced by the atoms. These are the sorts of things that are normally done as a matter of course when operating these masers.