ONE WAY TIMETRANSFER VIA METEOSAT CAPABLE OF 30 NS ACCURACY

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ABSTRACT

A pilot project under joint development of the Institut für Angewandte Geodäsie (IfAG) and Physikalische Technische Bundesanstalt (PTB) supported by the European Space Operation Center (ESOC) makes use of the METEOSAT ranging signal, available every 3 hours for about 1.5 minutes. The phase of the ranging signal is measured against the second pulses of the station clocks. A system study shows that the accuracy obtainable could be in the order of 30 ns. The receiver unit consists of a 2 m diameter fixed antenna, a low noise broadband receiver and a phase tracker and demodulator, the overall costs will be less than $ 20 000 US.

1. ACKNOWLEDGEMENT

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2. GENERAL REMARKS

Precise measurements for geodetic applications using space techniques such as laser ranging to artificial satellites or to the moon, very long baseline interferometry (VLBI) and Doppler observations require precise time and time interval measurements. Therefore the local clocks of the observation stations must be linked to a coordinated time scale such as UTC with high accuracy. The laser ranging technique which meanwhile achieved time interval measurements with an accuracy of better than 100 ps (~1 - 2 cm) /5/ requires a real time determination of the epoch of the range-observations within a global frame better than 1 µs /3/. As within short time routinely no time-transfer of high accuracy could be performed, except portable clock trips /1/, which are laborious, time-consuming and expensive, or time transfer via TV /1/ which could not be applied between Wettzell (IfAG) and Braunschweig due to the large separation and the non-existence of a common transmitter, the local clocks have to extrapolate the timescale within the desired accuracy up to the moment of observations. This procedure requires that the local clocks must be synchronised several days before to a high performance coordinated timescale of a time laboratory with an accuracy of better than 100 ns.

In Cooperation between the Physikalische Technische Bundesanstalt (PTB), the European Space Operation Centre (ESOC) and the Institut für Angewandte Geodäsie (IfAG) it is planned to carry out a oneway time transfer via the geostationary satellite METEOSAT /2/. The accuracy could be expected to be better than 50 ns. As the position of METEOSAT is about 0^{o} latitude and 0^{o} longitude the application area is limited and the accuracy of the procedure is dependent on the location of the participating stations.

For this paper the procedure of the time transfer is discussed and an error budget for the transfer between Wettzell and Braunschweig is estimated.

3. PROCEDURE OF THE TIME TRANSFER

The principle of the procedure is similar to that used for TV-time transfers with the main-difference that the transmitter is located in a satellite. The main problem in one way time transmissions from a satellite is the accuracy with which its position must be known. A geostationary satellite offers the advantage of small relative movements but normally the mission requirements do not include a very accurate orbit determination. An exception in this field is the satellite METEOSAT of which the 2-point-ranging system allows orbit determination to the order of 100 m accuracy. A disadvantage is the long distance to the satellite which causes the received signal to be rather weak (in comparison to a TV signal). However, a special format of the timing signal allows averaging it for long periods of time and thus to reach the high accuracy in time coordination required. Investigation of the different transmissions from the satellite resulted in the conclusion that the "ranging signal" should be the best for the time transfer. The carrier frequency of the ranging signal is 1.691 G Hz phase-modulated with a

160 kHz sinewave. For the resolution of ambiguity of the zeropoint crossings an additional pseudo-random-noise of 20 k bit/s (1000 bit Code; period 50 ms) synchronous with the 160 kHz-frequency is modulated onto the carrier (both signals are derived from a local atomic standard). Every three hours for a period of 1.5 minutes the ranging signal is transmitted from the ESA-ground station at Michelstadt (Fed. Rep. of Germany) for orbit determination of METEOSAT. For our application this ranging signal is also received at the ground stations Wettzell (W) and Braunschweig (B) after being transpondered by the satellite (figure 1).

For the time comparison the 160 kHz signal will be used. As the duration of one period is 6.25 µs it is necessary to synchronise the clocks undergoing comparison within half of the duration (of 3.125 µs) in order to identify the zeropoint-crossings without decoding the pseudo-random noise. At the stations the time interval T between the local second pulses and the subsequent zeropoint crossing of the received 160 kHz-signal has to be measured. The time difference δ of two participating clocks, here the institutions in Wettzell (W) and Braunschweig (B), can be derived from figure 1 and 2. It has to be distinguished between the two situations (a) and (b) of figure 2 characterised by the fact of perhaps one unknown period P of the 160 kHz signal. The ambiguity of that one period can be resolved if the time difference between "B" and "W" is known to better than half the period P. From figure 2 the following formula can be derived:

$$\delta + T_W + \tau_{SB} - \tau_{SW} = T_B + n\,P,$$

with

T_W, T_B: measured time interval between the second pulse and the subsequent zeropoint-crossing of the 160 kHz signals at Wettzell (W), resp. Braunschweig (B),

τ_{SW}, τ_{SB}: propagation delay between the satellite and Wettzell, resp. Braunschweig, derived from the coordinates of the satellite and the earth station.

n : integral number of periods P = 6.25 µs contained in the difference of the propagation delays ($\tau_{SB} - \tau_{SW}$).

"N" (figure 2) characterises one **positive zeropoint-crossing** of the 160 kHz signal transmitted at one point of time by the satellite and received by the earth stations **at different points of time.**

4. THE RECEIVING STATION

Figure 3 shows the block diagram of the receiving station. The RF- and IF-portion of the receiver is of low noise phase compensated, broadband design mounted in a weatherproof box on the rear side of the antenna. The technical design of that part of the receiver which extracts the 160 kHz tone from the 70 MHz - intermediate frequency is closely related to the design of the receiver ESOC is using for ranging.

The phase lock loop (PLL) for the 160 kHz tone at ESOC is designed with a natural frequency of 15 Hz. With the signal to noise ratio of 61.2 dB.Hz (table 1), estimated for a 2 m diameter parabolic antenna that PLL causes a timing jitter of 14 ns RMS. However, in view of the scheduled correlation with the second pulses of atomic clocks a reduction to 2 ns appears attractive and will not create technological problems. The overall cost of the receiving station is expected to be less than $ 20 000 US.

5. ERROR ESTIMATION

5.1 Random timing error of the ranging signal

As mentioned in chapter 3 the estimation of the signal to noise ratio leads, up to now, to about 14 ns RMS timing jitter. As during a period of 90 s up to 90 measurements will be available and about 90 values for δ (chapter 2) will be calculated the average of all will decrease the mentioned timing error of 14 ns for a single measurement to less than 2 ns, provided that the correlation between the data is as small as expected.

As the measurements are performed with different zeropoint-crossings of the 160 kHz signal (figure 2) there may occur the influence of the oscillator noise. As the 160 kHz tone is derived by local atomic frequency standards, it is expected that the influence is less than the other random noise contributions. If it is recognised in the first experiments that the noise is too strong, it will be simply omitted by identifying and using the same zeropoint-crossing ("N", figure 2).

5.2 Positioning errors

From the geometrical point of view errors in the coordinates of the stations and of the satellite will influence the accuracy. With the Doppler technique point-positioning for the observation stations and for the METEOSAT-tracking station with an accuracy of 1 m is possible. The position of METEOSAT will be known with an accuracy of the order of about 100 m. However, it should be kept in mind that the orbit determination is an order of magnitude better than the METEOSAT-mission requires and it is not self evident to be obtainable on follow-on spacecraft.

Expressing the range-differences $\Delta S = C\,(\tau_{SB} - \tau_{SW})$ in terms of coordinates of the station and of the satellite the differentiation of that expression permits the estimation of the influence of these inaccuracies. Assuming random errors the following formulae yield the estimations

a) for errors in the groundstation positions

$$\overset{P_1P_2}{m}_{\Delta\delta} = \frac{1}{c}\sqrt{\sum_{i=1}^{3}\left(\left(\frac{\overset{P_1}{x}_i - \overset{Sat}{x}_i}{S_1}\right)^2 d\overset{P_1}{x}{}_i^2 + \left(\frac{\overset{P_2}{x}_i - \overset{Sat}{x}_i}{S_2}\right)^2 d\overset{P_2}{x}{}_i^2\right)}$$

b) for errors in the satellite position

$$\overset{Sat}{m}_{\Delta\delta} = \frac{1}{c}\sqrt{\sum_{i=1}^{3}\left(\frac{\overset{Sat}{x}_i\,(S_1 - S_2) - S_2\overset{P_1}{x}_i + S_1\overset{P_2}{x}_i}{S_1 \cdot S_2}\right)^2 d\overset{Sat}{x}{}_i^2}$$

with

$\overset{P_1}{x}_i$: coordinates of the first groundstation

$\overset{P_2}{x}_i$: coordinates of the second groundstation

$\overset{Sat}{x}_i$: coordinates of the satellite

S_1 : range from station 1 to the satellite

S_2 : range from station 2 to the satellite

dx_i : errors in coordinates.

Inserting approximations for the coordinates of the stations (B and W) and the satellite position the geometrical influence is of the order of 5 ns from the observation stations and 5 ns from the satellite. In the period from 5th to 15th November a Doppler campaign including the participating stations and moreover some of the European time laboratories has been carried out with the objective of computing precise station coordinates.

5.3 Ionospheric refraction

The uncertainty due to the ionospheric refraction will be very small. The total influence of the ionosphere for a frequency of about 1.7 G Hz observed with an elevation of 30^{o} is about 3 m. With the aid of an ionospheric refraction model this effect will partly be corrected in the computation of the propagation delays τ_{SW} and τ_{SB}. As it can be assumed that the influence in Wettzell and Braunschweig is similar the ionospheric effect can be neglected. It amounts to less than 1 ns.

5.4 Tropospheric refraction

The largest uncertainty will be due to tropospheric refraction as the meteorological conditions in Wettzell and Braunschweig can be expected to be different. In a study performed by "Stanford Telecommunications INC" /4/ for the production of the GPS-receiver for time transfers, the uncertainty due to the ionosphere and to the troposphere together was estimated to be 30 ns for a frequency of 1.575 G Hz. As the carrier frequency of 1.691 G Hz differs little from the GPS-frequencies, 30 ns for refraction can be assumed for this project. The influence of the ionosphere (~ 10 ns) is to be subtracted thus only about 25 ns have to be taken into account for the tropospheric refraction.

5.5 Uncertainty due to the groundreceivers

The receivers used at the various sites should be identical in their IF-conception. Since this excludes the use of narrow filters in the signal (tone) path a stability requirement of 10 ns is expected to be feasible. Initially, and also at regular intervals it is possible to calibrate the receiving equipments at the ESA ground station where the received signal is much less contained with noise because it has a 15 m antenna. No influence can be expected to result from different temperatures at the stations between the high frequency part of the antenna and the preamplifier. The other parts of the receiver will be installed in a room, if possible with air conditioning, so that this influence should not be more than 5 ns. The total uncertainty should be less than 15 ns.

5.6 Error budget-Summary

Table 2 summarises the errors of the previous chapters. Assumming random influence of the estimated errors an accuracy of about 30 ns for a time transfer during a ranging period could be expected. As the measurements could be done every 3 hours (8 times per day) further averaging over a day probably leads to the total uncertainty of 20 ns for a daily time transfer.

6 REFERENCES

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1.	Carrier frequencies	1691.00 MHz
2.	Worst case effective radiated power	18.10 dBW
3.	On board received signal to noise power density ratio	74.63 dB.Hz
4.	Atmospheric loss (at ≈ 30° ground antenna elevation)	0.07 dB
5.	Ground antenna feed and cabling loss	0.10 dB
6.	System noise : - cosmic noise	8K
	- low noise amplifier, F=2.5 dB	233.5K
	- atmospheric + cabling loss (0.17 dB)	11.5K
	- Sidelobes, illuminating earth	15K
	- TOTAL 268K	24.28 dBK
7.	Propagation loss $(\frac{1}{4\pi\ d^2})$ d=39.000 km	162.81 dB
8.	Receiver input power for a 2 m parabolic antenna with 50% efficiency	-142.92 dBW
9.	Gain of above antenna at 1961 MHz	27.97 dB
10.	Received signal to noise power density ratio, ignoring retransmitted uplink noise	61.4 dB.Hz
11.	Overall signal to noise density ratio (from 3 and 10)	61.2 dB.Hz
12.	Modulation loss	-7 dB
13.	PLL Bandwidth	20.0 dB.Hz
14.	Signal to noise ratio in the PLL	34.2 dB
15.	Jitter	14 mrad.
16.	RMS timing error	14 ns

Table 1, Estimation of the overall signal to noise density ratio.

uncertainty	in ns
1. random timing error	2
2. position of the ground station	5
3. position of the satellite	5
4. ionosphere	-
5. troposphere	25
6. ground receiver	15
	$\sqrt{\sum \mu_i^2} \approx 30$ ns $\sum \mu_i \approx 50$ ns.

Table 2, error budget

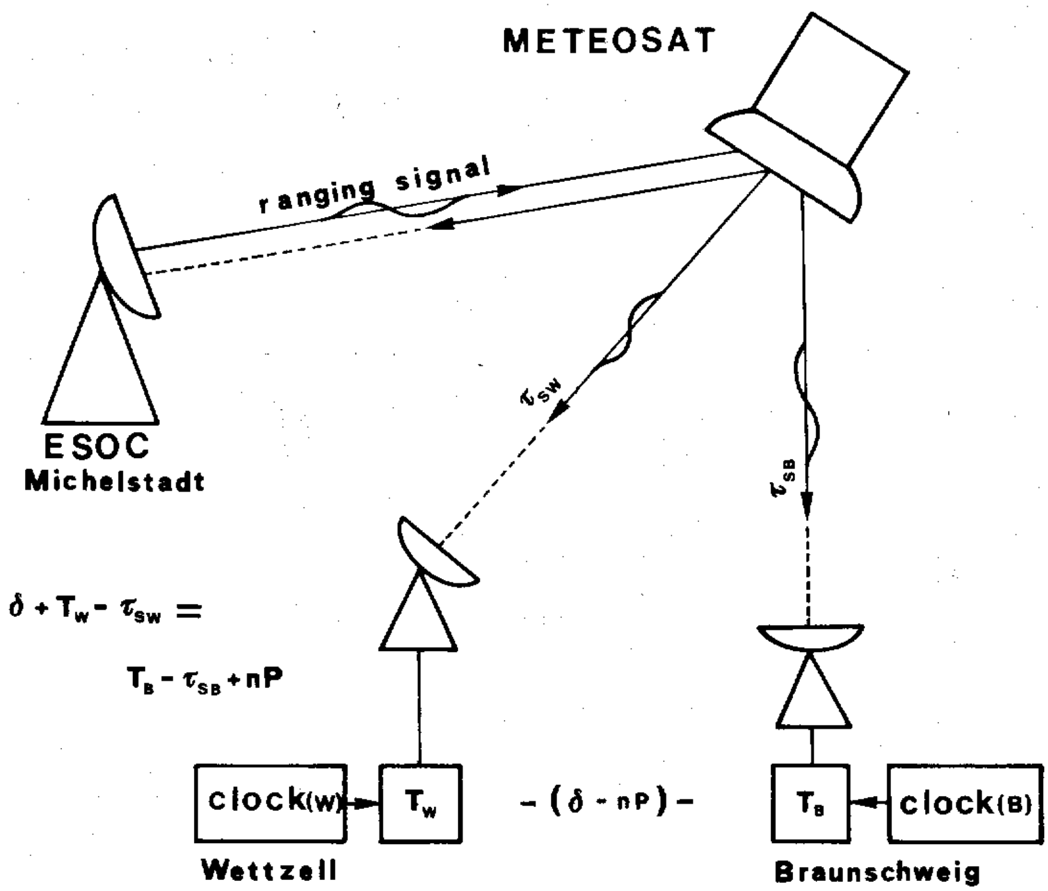

figure 1, scheme of the time transfer

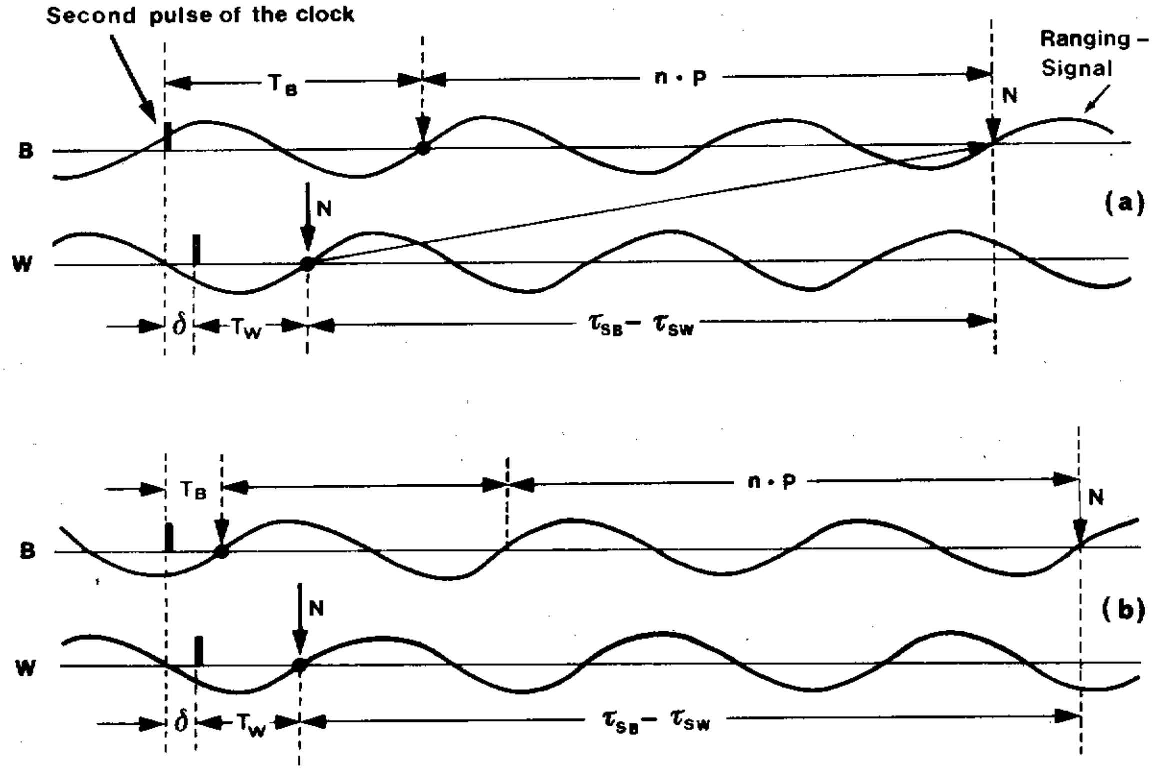

fig. 2, computation of the clock difference δ

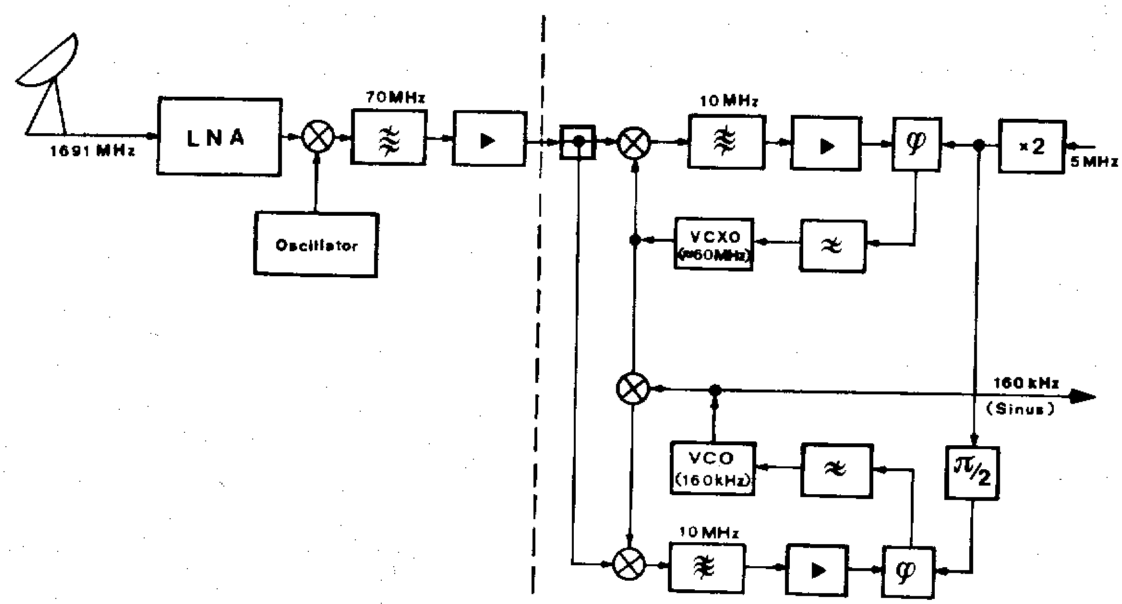

fig. 3, Block diagram of the receiver.

QUESTIONS AND ANSWERS

MR. PLEASURE:

You assumed random--

DR. SCHLUETER:

Yes.

MR. PLEASURE:

But have you made a spectrum analysis of the frequency given?

DR. SCHLUETER:

No, we assumed it. We assumed random errors.

MR. PLEASURE:

Yes. Well the standard technique is, for chemical engineering and most other types of engineering is to put a spectrum analyzer on it and you may find that you have got 60 cycle hum from nearby motors or something and if that is the case you are going to be in a larger error and then you have less than you were projecting.

DR. SCHLUETER:

Well this is a project we proposed that we have not yet experiences with it.

DR. BARTHOLOMEW:

In your error budget you showed 25 nanoseconds for a tropo uncertainty. That looks a little bit large to me. I didn't realize that.

DR. SCHLUETER:

If it isn't too large it is better for the error projections.