REVIEW OF ESA TRACKING FACILITIES AND THEIR CONTRIBUTION TO THE ORBIT DETERMINATION

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ABSTRACT

The paper gives an overview of the current ESA tracking facilities operating in S-Band and higher frequencies. The current tracking facilities consist of 3 systems: the Tone Ranging, the DATTS and the DSTS. Tracking measurement types are range, Doppler and antenna angles. Practical knowledge was gained during the operation of several satellites and the performance experienced is described. The usefulness of these tracking measurements for the satellite position determination of some common orbit types is briefly discussed.

Keywords: Tracking Network, Range, Doppler, Angular Data, Orbit Determination Accuracy.

1. INTRODUCTION

Satellite operations began for ESOC/ESA in May 1968, but since then the ground tracking facilities have been upgraded several times. In the beginning mainly polar close earth orbiting satellites were supported, and the ground stations were used essentially for telecommanding and reception (VHF) of play-back data. The stations were spread all over the world, the polar regions obviously being of greater importance. The whole network comprised stations of 4 organisations. The geographical position of the 23 stations involved is shown in Figure 1. The organisations which formed the network were:

ESTRACK	with Fairbanks, Falkland, Redu, Spitsbergen
CNES	with Kourou, Canary Islands, Ouagadougou, Brazzaville, Pretoria
NTNF	with Tromsø
NASA	with Hawaii, Ulaska, Rosman, Fort Myres, Quito, Lima, Santiago, New Foundland, Winkfield, Johannesburg, Tananarive, Carnarvon, Orroral

For the sake of completeness the current network (stations underlined) is also indicated on Figure 1.

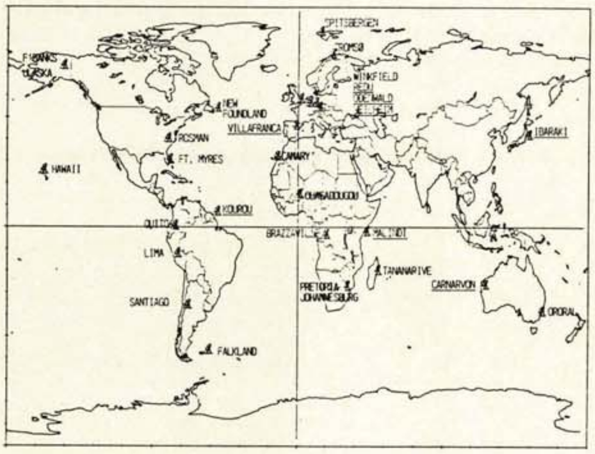

Figure 1. Ground Station Network

Compared to the data reception less demand was put on the tracking itself. Tracking was carried out by means of interferometer from 14 out of 23 stations. The performance of this system was about 200 µrad for each of the two components ℓ and m. This was adequate since the orbit determination accuracy requirements were not very stringent, i.e. about 5 - 10 km for the first satellites launched in the years 1968 and 1969.

However, during the following years the requirements for a more accurate spacecraft position increased. The trend of the requirements for highly eccentric orbiting satellites can be seen in the following example:

Satell.	Launch	Initial Orbit Apogee height	 Incl.	 Arg. of perigee	Position requirem.
HEOS-A1	1968	215 000 km	73°	265°	500 km
HEOS-A2	1972	235 000 km	88°	295°	100 km
COS-B	1975	86 000 km	98°	275°	75 km
EXOSAT	1983	190 000 km	72°	285°	1 km

The increase in requirements forced improvements not only in the area of tracking, but also in the area of the orbit determination, where methods and models had to be updated. Examples are the earth rotation including nutation and polar motion

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for the ground station expressed in the inertial coordinate frame, and the propagation delay due to the ionosphere for the tracking measurements.

The paper gives an overview of the current ESA tracking facilities (range, Doppler and angles) and the performance that we have experienced with each. In addition a summary of the achievable orbit determination accuracies for commonly used orbit types is given. The paper concludes with a comparison of the usefulness of the three tracking types for geostationary transfer and synchronous orbits.

2. CURRENT TRACKING NETWORK

Within this overview only UHF and higher frequency tracking systems are considered. VHF tracking facilities are not considered since they will soon be phased out.

The ESA tracking systems include three types of measurements:

- range (tone ranging together with pseudo-random sequence)
- Doppler (in fact, integrated Doppler) and
- antenna angles.

These types of tracking data were obtained from 8 ground stations, either owned by ESA or used by ESA under contract. The configuration is listed in Table 1. The antenna locations refer normally to the intersection of the azimuth and elevation rotation axis, because this point is independent of the antenna dish direction. This location is surveyed relative to the station reference point, which in most cases is measured by Doppler tracking of the US Navy's Transit Satellites to an accuracy of better than 5 m. The reference point is expressed in the WGS-72 coordinate system using an equatorial earth radius of 6378.144 km and a flattening coefficient of 1/298.257.

As can be seen from Table 1 experience was gained with these three tracking types from a highly eccentric orbiting satellite (EXOSAT, 1983 - 1986, apogee height 190 000 km, inclination 72°, arg. of perigee 285°), an interplanetary flight (GIOTTO, 1985-1986, comet Halley as target) and with 6 geostationary satellites:

Satellite	year of launch	current orbit longitude	current orbit inclination
OTS-2	1978	5° + .50°	2.9°
METEOSAT-2	1981	0° + 1.00°	<.3°
MARECS-A	1981	178° + .15°	.8°
ECS-1	1983	13° + .10°	<.1°
ECS-2	1984	7° + .10°	<.1°
MARECS-B	1984	-26° + .15°	2.0°

It should be mentioned that the positions of the two MARECS satellites were switched during the beginning of 1986.

Station	Geographical Location		Frequency used by Tracking Facility					Satellite Supp.							
	Longitude	Latitude	Tone ranging	Pseudo-random DATTS[1]	Pseudo-random DSTS[2]	Doppler DSTS[2]	Angle	OTS	MET	MAA	MAB	EC1	EC2	EXO	GIO
Kourou, Fr. Guyana	-52.8051°	5.2531°		S					X						
	-52.6404°	5.0988°	S[3]											X	X
Villafranca, Spain	-3.9532°	40.4439°	Ku					X				X	X		
	-3.9526°	40.4457°	S											X	
	-3.9517°	40.4446°	C				C			X	X				
Redu, Belgium	5.1453°	50.0021°					Ku	X				X	X		
	5.1457°	50.0016°	Ku					X				X	X		
Odenwald, W. Germany	8.9749°	49.7127°		S					X						
Weilheim, W. Germany	11.0782°	47.8811°			S,X[4]	S,X[4]									X
Maldini, Kenya	40.1943°	-2.9956°	S											X	X
Carnarvon, Australia	113.7064°	-24.8662°	S											X	X
	113.7064°	-24.8662°			S,X[4]	S,X[4]									X
Ibaraki, Japan	140.6927°	36.6969°	C				C			X	X				

[1] Data Acquisition, Telecommand and Tracking Station
[2] Deep Space Tracking System
[3] The Kourou S-Band Tone Ranging System belongs to CNES and has been built by a different company
[4] There are two frequency possibilities, S-Band up and down or
S-Band up and X-Band down

Table 1. Current Tracking Facilities and their Utilisation

As the amount of data per tracking pass is rather low in most of the cases the entire volume of measurements is tranferred to ESOC. An exception was the DSTS Doppler for GIOTTO, which required some preprocessing at the ground station because of high data rate and long passes (1 point every 0.1 sec for about 10 hours). These two modi of operations will be briefly described below and are illustrated in Figure 2. A further exception is the angular measurements which are contained in the Remote Monitoring Message. This message is sent from the ground station to ESOC as often as every 2 sec. during the entire support period.

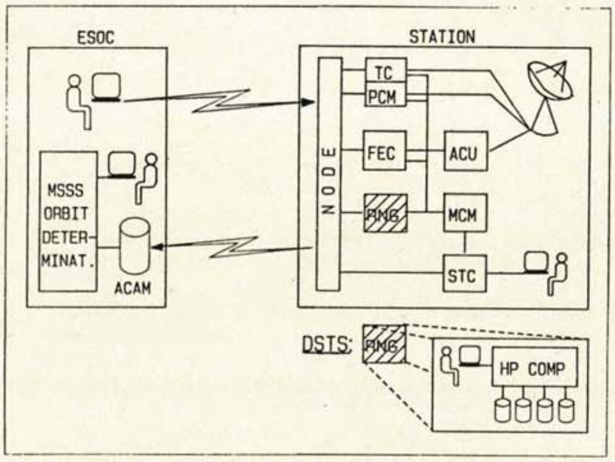

Figure 2. Modes of tracking operations

2.1 Transfer of Raw Tracking Data To ESOC (Tone Ranging as Example, Ref. 1)

Provided the ground station is configured properly, the entire tracking operation is carried out under remote control from ESOC. The spacecraft controller initiates the tracking operation with the Transaction Request Message and after execution the data is transmitted in the Transaction Response Message from the ground station to ESOC. The data are accumulated on an ACAM (Assisted Circular Access Method) file which always contains the last few days' data.

The amount of data involved are:

Type	pass duration min.	no of points	time increment sec.	message length bytes
Tone ranging				
old format	< 2	128	≈.125	532
new format	< 2	32	.250	356
DATTS ranging				
(2way + 4way)	< 2	320+320	.100	5440

2.2 Transfer of Preprocessed Tracking Data to ESOC (DSTS as Example)

In the case of DSTS, preprocessing is required at the ground station for two reasons: first, the volume of the raw data is too great and secondly, the actual Doppler shift has to be extracted from the Doppler data for successful ranging operations. For this reason, the tracking operation is initiated from ESOC and all the measurement data (comprising meteorological, range, raw and smoothed Doppler data) are stored at the station on disc. It should be mentioned that the data files are overwritten with each new pass taken. The data can be transmitted to ESOC in near real time or play-back mode.

The amount of data involved are

	Sampling sec.	Meas./ Record	Time duration of Record sec.	No. of records/ hour
Meteorol.	10	50	500	7
Range	10	24	240	15
Doppler raw	0.1	100	10	360
(Doppler compressed			600	6)
	No. of records per hour about			390

3. TRACKING SYSTEMS

The ESA tracking systems can provide antenna angles, range and Doppler measurements. As mentioned in Table 1 three systems plus the ground antennae are available:

- Tone Ranging
- DATTS Ranging (Data Acquisition, Telecommand and Tracking Station)
- DSTS Ranging and Doppler (Deep Space Tracking System) and
- Angular Data.

For the range and the Doppler, if not explicitly stated, the 2-way values are normally quoted for the performance and for the ambiguity. The performance shown in the following figures is the dispersion of the raw data compared to the smoothed data points.

3.1 Tone Ranging System (Ref. 2)

The Tone Ranging System was designed as a general ranging system for various orbit types and satellites. It was developed in 1980/81. This method of determining the distance between satellite and ground station consists of measuring the time delay between

- a sinusoidal signal transmitted by the ground station to the satellite and the
- corresponding signal transponded from the satellite and received at the ground station.

The total measured delay is the sum of

- the two-way distance between ground station and spacecraft,
- the delay in the signals through the station,
- the delay in the transponder on board the satellite, and
- the additional delay due to atmospheric diffraction of the transmitted and received signals.

The measurement method imposes no limitations on the selection of the frequency of the signal to be used. Accuracy considerations, however, lead to the selection of a relatively high frequency, the upper limit being defined by spectrum-occupancy considerations. This implies that more frequencies of the measuring signal will be required to cover the two-way distance between the tracking station and the satellite. Consequently, before the actual measurement takes place, it is necessary to establish a correspondence between transmitted and received signals. This is obtained by transmitting in sequence, together with the measurement signal (major tone), a set of lower frequency signals (minor tones) for the ambiguity resolution.

The frequencies used in the tone-ranging system are: 100 kHz (major tone), 20 kHz, 4kHz, 800 Hz, 160 Hz, 32 Hz and 8 Hz (minor tones). The 8 Hz minor tone serves as the time-base reference for all the other tones.

To limit the transmitted modulation spectrum, the frequencies actually transmitted are 100 kHz (major tone) and 20 kHz, 16 kHz, 16.8 kHz, 16.16 kHz, 16.032 kHz and 16.008 kHz (minor tones). The sequence of the transponded tones is shown as a function of time in Figure 3.

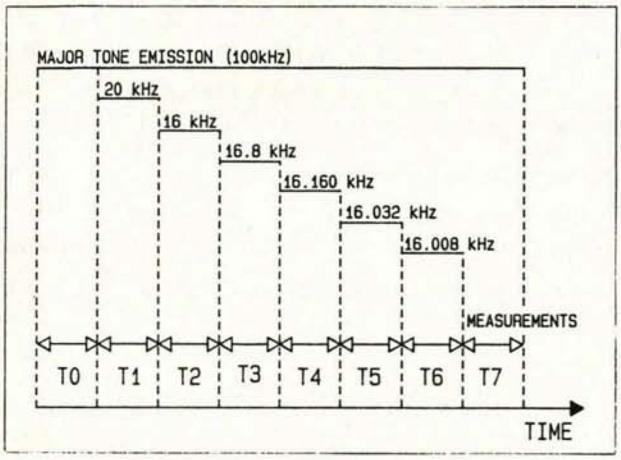

Figure 3. Sequence of ranging tones

The time T0 is the time required to lock the station receiver onto the received carrier and the ranging demodulator onto the transponded major tone. T1 to T6 is the time required for ambiguity resolution.

The range measurement is then performed during time T7 by measuring the time delay between the 8 Hz reference tone and the 8 Hz reconstituted tone. Since 8 Hz is the lowest tone used, the system has an ambiguity of 37500 km. Every 250 msec a measurement is available to the control unit for formatting. Each format (Ref. 1) contains the results of 32 successive measurements (one group of measurements) and the time at which the first measurement in the message was started.

The performance of this ranging system is given in Figure 4.

It should be added that an earlier system of this type still exists with a different format containing 128 measurements incremented by about 125 msec.

3.2 DATTS Ranging System

The DATTS Ranging System is a dedicated tracking system, designed for the METEOSAT satellite (launched in November 1977) and specified to work in a predefined station environment. The choice of the system design was determined by the

- requirement for precise satellite position, and the
- limitation of the radiated flux below the ITU recommendation for the Odenwald Station.

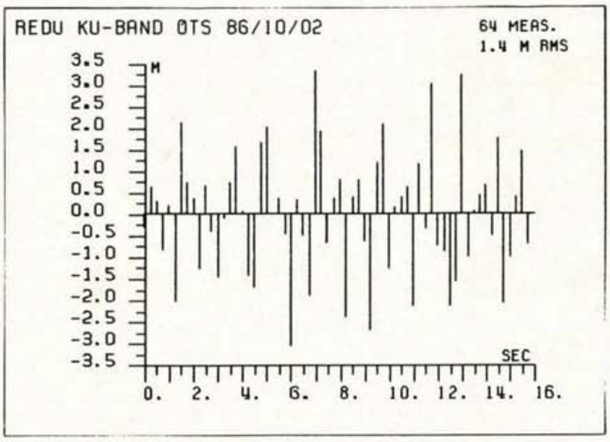

Figure 4. Performance of tone ranging

This led to the conception of a tone ranging system using a pseudo-random sequence for the ambiguity resolution.

The range measurements are derived from the phase delay of a 160 kHz tone. A pseudo-random PCM code, multiplexed with the tone serves the dual function of ambiguity resolution and reduction of the power flux density of the various spectral components. With the used pseudo-random sequence the ambiguity in the time measurement is 50 msec leading to a range ambiguity of about 15000 km. The system involves the DATTS ground station at Odenwald, a land-based transponder (LBT) at Kourou (Odenwald and Kourou provide a good geometrical baseline), and uses the two dissemination transponders on board the METEOSAT satellite. The signal path is given in Figure 5.

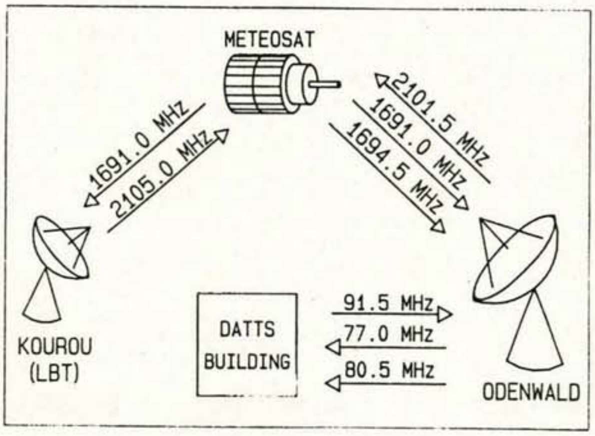

Figure 5. DATTS signal paths

From the DATTS the 160 kHz tone, interplexed with the pseudo-random sequence and modulated in the uplink RF carrier of 2101.5 MHz, is transmitted to the satellite. In the satellite the uplink frequency is converted to 1691 MHz in the first dissemination transponder and redisseminated. This signal is received

- at the DATTS where, after demodulation, it is used to determine the 2-way ranging (DATTS-Satellite-DATTS) by measuring the phase delay

between the transmitted and received 160 kHz tone,
- at the LBT, where it is further converted and retransmitted to the satellite at 2105 MHz. This signal is redisseminated by the second transponder at a frequency of 1694.5 MHz. It is then received at DATTS and demodulated. This provides the 4-way ranging measurement (DATTS-Satellite-LBT-Satellite-DATTS).

However, before the actual measurements over the LBT can start, the LBT has to be switched on. This is done by transmitting a short burst of the ranging signal. At detection of the 160 kHz tone in the land-based transponder the transmitter filament is switched on. A duration of about 3 min is required to stabilize the filament emissions before the high-voltage can be applied to the tube. Consequently ranging can only start 3 min after the detection of the 160 kHz tone. After that burst the measurement sequence consists of
- precalibration receiver 1 with 4 seconds transmission
- precalibration receiver 2 with 4 seconds transmission
- ranging measurement with 64 seconds transmission, alternating for 2 seconds on each receiver starting with receiver 1
- postcalibration receiver 1 with 4 seconds transmission
- postcalibration receiver 2 with 4 seconds transmission

The measurements are provided with a resolution of 10 nsec and the overall measurement accuracy of the system lies in the order of 1 m. A typical example of the performance is given in Figure 6.

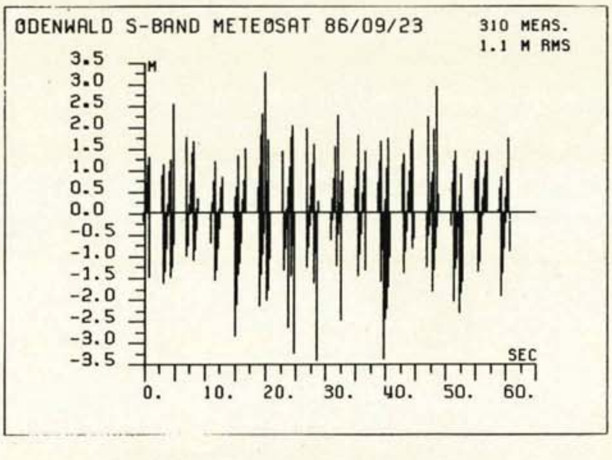

Figure 6. Performance of DATTS ranging

3.3 Deep Space Tracking System

The design of the Deep Space Tracking System (DSTS) was determined by the first deep space mission of ESA, viz. GIOTTO, which was launched in July 1985.
Because of the mission network support requirements, the interfaces of this new system were standardised so that it could be used in any station environment with minimal adaptation. The design requirements of the system were:
- capability of the system to cope with extremely low received S/N ratios which are caused by high signal losses in the spacecraft-ground station link due to the extreme distances;
- accurate determination of Doppler shift and Doppler rate in order to predict the downlink frequency at the reception of the transponded signal.

The two above requirements are complementary in that the bandwidth of the tone recovery receiver can only be optimised (narrowed) if the exact received frequency is known.

The DSTS is able to measure range and Doppler. Furthermore the system can process up to two Doppler signals simultaneously (e.g. calibration plus actual measurements). For the Doppler measurements it is necessary that the transponder operates in coherent mode. A simplified block diagram is given in Figure 7. Whereas the uplink is always carried out in S-Band, the downlink can either be in S-Band (ratio 240/221) or in X-Band (ratio 880/221).

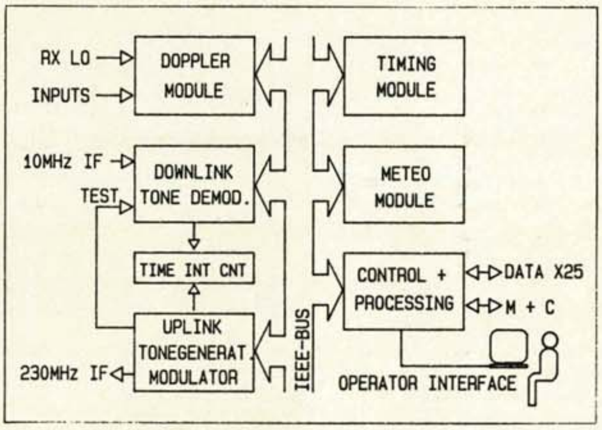

Figure 7. Simplified block diagram of DSTS

Ranging measurements are performed with a range tone. The ambiguity resolution is established by means of pseudo-random codes, coherent with the major tone and of variable length. The ranging equipment measures an ambiguous two way time delay of the signal. The ambiguity (range gate) depends on the selected amount of periods which can lie between 2^{10} and 2^{21}. It also depends on the actual tone period which can have a frequency between 100 kHz and 3 MHz. However, for GIOTTO this frequency interval was limited to between 500 kHz and 700 kHz. Consequently a range gate can generally be selected from about 100 km (when using 2^{10} periods of a tone with a frequency of 3 MHz) up to about 6.3 million km (when using 2^{21} periods for a frequency of 100 kHz). The measured time delay is quoted in units of 1 nsec. An example of the performance of the data with low S/N ratio is given in Figure 8.

The integrated Doppler is obtained by measuring the total number of periods of the Doppler signal. Within the equipment two values are measured, i.e.:

- Time interval counter (Δt), giving the time between the 10 Hz UT reference signal and the first positive zero crossing of the receiver local oscillator signal. This signal is affected by the two-way Doppler effect once onboard transponder has locked onto the uplink carrier and

- total counter (N) giving the total number of periods of the translated Doppler signal. The maximal capacity of the counter is 2^{36}. However, the counter only displays the full value of the first measurement, the second measurement contains only the difference and the subsequent measurements indicate the difference of the differences, i.e. $N_1, \Delta N_2, \Delta\Delta N_3, \Delta\Delta N4, \ldots$ resulting in the following sequence for N_i

$$N_i = N_1 + (i-1)\,\Delta N_2 + \sum_{j=3}^{i} (i-j+1)\,\Delta\Delta N_j \quad (1)$$

The range rate can be derived from the following expression

$$\frac{\Delta N}{\Delta t} = f_{BIAS} - \frac{f_{rdown}}{c \cdot \Delta t} \int \dot{r}\, dt \quad (2)$$

where f_{BIAS} is a bias frequency
f_{rdown} is the reference downlink frequency
and c is the velocity of light.

An example of the Doppler performance is given in Figure 9.

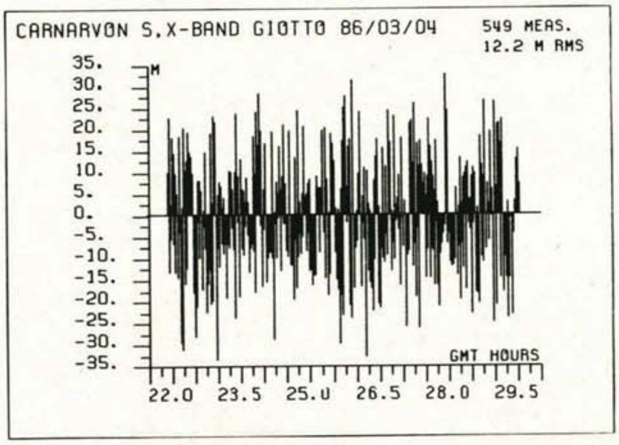

Figure 8. Performance of DSTS ranging

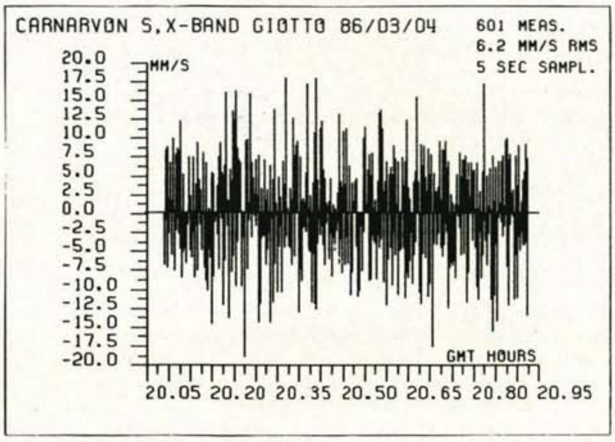

Figure 9. Performance of DSTS Doppler

3.4 Angular Data

When a station is operated from ESOC by remote control, some sort of feedback from the station is required. This takes the form of a Remote Monitoring Message, which also contains the actual antenna direction and is provided for the entire support period. Only the angular data, which are recorded in autotrack mode, i.e. following the maximal signal strength, can be used for orbit determination.

However, three points concerning the usefulness of these data should be noted:

- The antenna pointing data are required for normal spacecraft and station operations. The antenna must be pointed such that the signal of the satellite is acquired within the antenna beam (in the order of some 0.1°).
- The encoder will only read off the antenna direction with a given accuracy, which need not necessarily be very precise.
- The actual antenna orientation will be biased against the proper satellite direction not only because of alignment errors but also because of dynamic errors such as thermal effects, wind influence, etc.

The magnitudes of the dynamical errors depend on the one hand on the mechanical design of the antenna and on the other hand on the movement of the antenna required for the orbit type to be supported. It is obvious that a fast moving antenna is less accurate than the same antenna tracking a geostationary satellite. Therefore the precision of the antenna pointing can vary significantly. Values of the following magnitude have been experienced:

- Redu antenna for ECS (SHF) about 0.002° (Ref. 3) and
- Villafranca antenna for EXOSAT (S-Band) about 0.03°.

An example giving the performance of the MARECS antenna angles from Ibaraki in C-Band is given in figure 10.

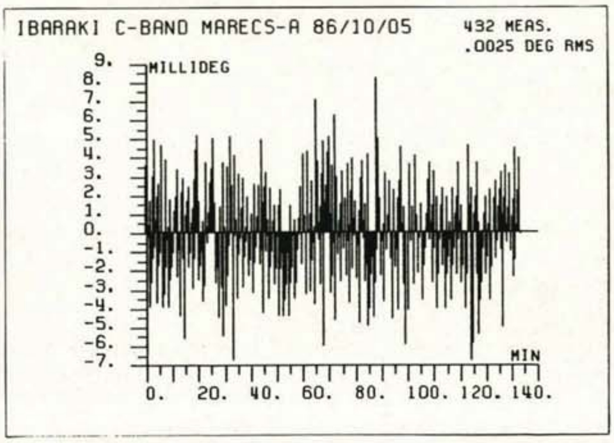

Figure 10. Performance of antenna angles

3.5 Summary of Tracking Performance

The computed RMS values given in the above figures are not the total measurement errors, since the values quoted are the RMS of the residuals of the smoothing process. There are additional effects which increase the residuals of the measurement in the orbit determination.

Range Measurements: The above figures show a performance of better than 2 m for the Tone Ranging and the DATTS and a significant larger value for the DSTS. However, the DSTS is not considered to be worse in performance than the other ranging systems; the increased RMS in this particular case is caused by the low S/N ratio because of the extreme distance to GIOTTO in March 1986. For lower distances the DSTS provides range data with an accuracy of about 1 m (Ref. 4) similar to the DATTS.

Integrated Doppler: The integrated Doppler is given by $\Delta N/\Delta t$ and seems to become more accurate with longer sampling times Δt as given below

Sampling time (sec)	1	2	5	10	60
RMS (mm/s)	18.0	10.6	6.2	4.1	1.7

However, it should not be concluded that the overall precision improves with longer sampling times. Modelling errors will occur; errors caused by atmospheric effects, for example, cannot be neglected for longer sampling times.
Under the assumption that the same dependency between performance and distance in the DSTS range is also valid for the integrated Doppler, one can expect RMS values in the order of 2 mm/s for a 1 sec. sampling time for lower distances.

Antenna pointing angles: It should be emphazised that the performance strongly depends on the mechanical antenna design and on the antenna movement. Values between 0.002° and 0.03° can be assumed.

Total RMS: These above given figures are not the total error to be expected within the orbit determination since they have been obtained as the result of the smoothing process. These values roughly represent the instrumentation error. Any slowly varying offset is ignored in the smoothing, but will be seen in the orbit determination and hence will increase the measurement residuals.

The following measurement errors can be assumed for S-Band frequencies:

	range	Doppler	angles
instrumentation (noise)	2 m	2 mm/s	.006°
troposphere	1 m	–	.003°
ionosphere	5 m	–	.001°
total RMS	6 m	2 mm/s	.007°

These figures are in agreement with the operational weekly orbit determination results. METEOSAT can be quoted as an example, where residuals are obtained in the order of 5 - 6 m for the 2-way measurements and 7 - 10 m for the 4 way measurements.

4. ORBIT DETERMINATION ACCURACY

The impact of the various tracking types on the orbit determination accuracy will be discussed with the help of two orbit examples, viz Geostationary Transfer Orbit and Synchronous Orbit.

In both cases S-Band tracking is assumed with the following performance for the random part

range	6 m
range rate	2 mm/s
angular data	0.007°

In addition to the random error an unknown, slowly varying offset caused by calibration errors, model inefficiencies, etc. is assumed, and can be in the order of

range	20 m
range rate	2 mm/s
angular data	0.005°

4.1 Geostationary Transfer Orbit

A typical example of a Geostationary Transfer Orbit, in this case of a satellite put into orbit by an Ariane launcher, is discussed here. The characteristic orbit parameters are:

perigee height	200 km
apogee height	36000 km
inclination	7°
longitude of initial descending node	10° West
period	10.5 hours

The ground station coverage from Kourou, Malindi and Perth is very good. Almost the entire first revolution is covered simultaneously by Malindi and Perth. The second and third revolutions have also good, but single station, coverage, first from Kourou then from Perth.

The orbit accuracy required for attitude control and AMF optimisation is very modest, about 25 km perpendicular to the apogee vector and about 4 km for the apogee radius. This requirement can easily be fulfilled by using the S-Band tracking (with or without Doppler) from the above-mentioned 3 stations.

However, of more interest is the first orbit determination shortly after injection. This orbit determination confirms if the launch was successful and the target orbit achieved. Experience has shown that the first meaningful result can be expected after about 90 min from injection. Obviously tracking is performed very frequently during this period, about every 5 to 10 min. whenever possible. There are of course gaps due to satellite manoeuvres or other important spacecraft activities.

For this early orbit determination range and Doppler measurements are essential, the angular measurements are of less importance because of their inaccuracy. To illustrate the importance of the various tracking types, the measurement errors are expressed as time errors. Of course this is a significant simplification, since the individual tracking types have different contributions to the orbit determination, but it gives some idea of the trend. The satellite movement seen from Malindi for the first 90 min after injection is:

time since inj. (min)	range (km)	range rate (km/s)	range acc. (km/s^2)	elev. (deg)	elev. rate (deg/s)
4	2590	-7.0	.012	4.4	.133
8	1550	.0	.045	59.4	.294
10	1760	3.8	.028	77.6	.000
16	4050	6.7	.000	42.8	-.048
30	9270	5.6	-.0014	23.7	-.011
60	18200	3.8	-.0007	13.6	-.0021
90	24000	2.8	-.0004	12.0	-.0005

If one takes the derivative of the measurements for the computation of the corresponding timing error, one obtains for the first line (injection plus 4 min)

a range error of 6 m equivalent to 0.9 msec
a Doppler error of 2 mm/s equivalent to 0.2 msec
an angle error of .007° equivalent to 35. msec

It is clear that the Doppler measurements are very important close to perigee and become less important as the satellite moves away from perigee. Whereas the range data are essential throughout the orbit, the angle data do not improve the solution since the data are about 2 orders of magnitude worse than the range and Doppler data.

The achievable orbit determination accuracy is given below:

Tracking types used	Orbit ac. (3σ values) semi-major axis (km)	incl.	position (km)
- Tracking for the first 90 min every 10 min from Malindi and Perth			
range, Doppler, ang.	.10	.001°	.6
range, Doppler	.10	.001°	.6
range	.48	.004°	3.4
- Tracking for the first half revolution up to apogee 1 but with a half hour increment for the last 3 hours from Malindi and Perth			
range, Doppler, ang.	.03	.001°	.8
range, Doppler	.03	.001°	.8
range	.04	.001°	1.1

Range and Doppler are the essential tracking types for the initial transfer orbit determination.

If 2 stations are available, angle data can be omitted.

4.2 Synchronous Orbit

The synchronous orbit determination is very often based on a two station ranging configuration or on a dedicated station measuring range and angles. Doppler data are not useful because of the rather small range acceleration within a synchronous orbit.

Some typical orbit determination accuracies are given below. The precision of the reconstituted measurement is derived from the covariance matrix calculated in the orbit determination. This is done for the prime tracking station only. The full tracking configurations for the satellites mentioned are given in Table 1.

	Satellites			
	OTS-2	MET-2	MAR-A	MAR-B
Orbit accuracy				
S.-m. axis (m)	4	2	5	5
Position (m)	600	100	1400	1600

Precision of reconstituted measurements for

prime station	Redu	Odenw.	Ibaraki	Villaf.
range (m)	6	5	8	8
range rate (mm/s)	.6	.25	1.0	.8
angles	.007	.0001	.004	.004

As can be seen from the figures above, the prime tracking systems for synchronous orbits are ranging facilities supported by antenna angles. Doppler systems are not important because the station-satellite configuration changes only very slowly.

5. FUTURE DEVELOPMENT

As mentioned earlier three tracking systems are available, viz the Tone Ranging, the DATTS and the DSTS. Whereas the Tone Ranging will remain unchanged for the tracking of the geosynchronous communication satellites (OTS, MARECS and ECS), the two other systems are in the process of being upgraded.

An updated DATTS system will be used for the new generation of METEOSAT Operational Satellites (MOP). A new ranging concept was required because the second dissemination transponder on board was not sufficient for group delay variations and signal levels. The new system will have only one transponder, the payload transponder (MPT), for satellites in operational use. In addition, the standard S-Band transponder (MST) will be used for satellites in hibernation. In the updated DATTS, a pseudo-random sequence will be transmitted with a signal below the noise, and the two-way and four-way delay will be measured after acquisition and tracking of the coded signal. Two different codes (in order to distinguish between the two-way and the four-way mode) can be transponded simultaneously. As the S/N ratio of the ranging sequence is below the noise, ranging can in principle be carried out together with normal payload operations.

Validation tests of the updated DATTS system are planned for the beginning of 1988.

The DSTS system was designed for the deep space mission GIOTTO. This system is being upgraded to the Multi Purpose Tracking System (MPTS). The upgraded version will also be used for near earth satellites. The improvement mainly consists in a widening of the tone recovery loop bandwidth in order to cope with much larger Doppler shifts and rates without having to predetermine the exact received frequency.
The implementation of this system is planned for 5 stations (and in Weilheim for GSOC spacecraft control) for the time frame 1988-1990.

By that time the tracking configuration should be as follows:

System	Station	Long.	Lat.	Satellites
Tone Ranging (Range)	Kourou			MARECS (S-Band)
	Villafranca			ECS (Ku-Band)
	Redu			OLYMPUS (S-Band)
	Fucino	13.6°	42.0°	
	Ibaraki			
DATTS-MOP (Range)	Kourou (LBT)			METEOSAT (S-BAND)
	Odenwald			
MPTS (Range and Doppler)	Maspal.	-15.6°	27.8°	HIPPARCOS (S-BAND)
	Odenwald			EURECA (S-Band)
	Kiruna	21.1°	67.9°	ERS (S-Band)
	Malindi			
	Perth	111.8°	-32.0°	

Of course, angular data will be used in addition. In the future the S-Band tracking support for geostationary satellites will be provided by Kourou (Tone Ranging, CNES) plus Malindi and Perth (MPTS).

It should be mentioned that MPTS will also be used in the Inter-Orbit-Communication (IOC) package between OLYMPUS and EURECA. Tracking of EURECA will be carried out via the satellite OLYMPUS from the ground station Maspalomas. This experiment is oriented towards the later Data Relay Satellite (DRS).

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