Chapter 5 – DGPS INSTALLATION AND GROUND TEST

5.1 GENERAL

In this chapter we give a brief overview of typical DGPS installations. Particularly, some examples of aircraft and ground reference station GPS receivers/antennas, together with GPS programming and data processing software are presented. Furthermore, some information is provided about possible datalink installations, suitable both for telemetry and for DGPS correction data transmission.

The second part of this chapter also details the ground test activities required to support installation design and optimization.

5.2 EXAMPLES OF AIRCRAFT INSTALLATIONS

The general layout of an aircraft installation is shown in Figure 5-1. In this case, both an ASHTECH Z-12 surveying receiver and a TRIMBLE aviation receiver (TRIMBLE Air Navigation System – TANS) were fitted into the MB-339CD aircraft during development flight trials of new navigation systems (TACAN, VOR/ILS and INS/GPS navigation systems). Particularly, using a beam splitter, the same antenna was used for both systems, and a magnetic recorder was used for GPS and other FTI data gathering.

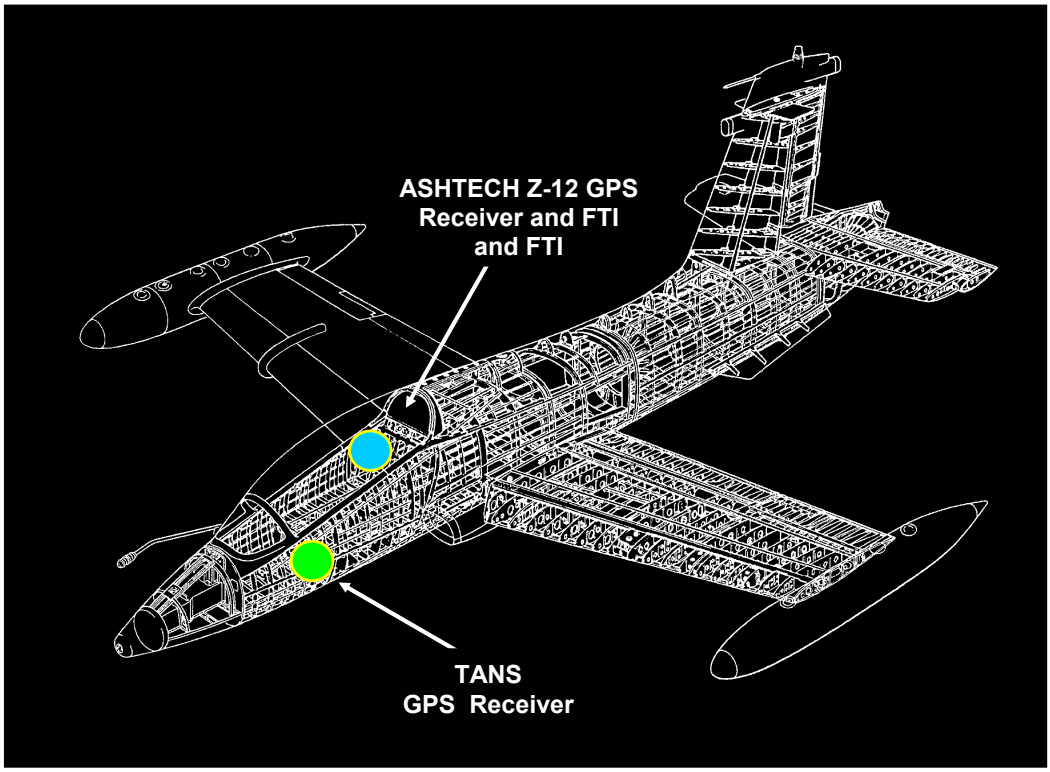


Figure 5-1: MB-339CD Aircraft DGPS/FTI Installation.

The airborne data-recording device used in the MB-339CD flight trials was a magnetic type recorder suitable for FTI use. Particularly, all required flight parameters (INS position, velocity, acceleration

components, etc.) from the FTI and TSPI data from both GPS receivers were recorded at a rate of about 200 Kbit/sec. A picture of the MB-339CD back-seat FTI rack installation (including the ASHTECH Z-12 GPS receiver) is shown in Figure 5-2.

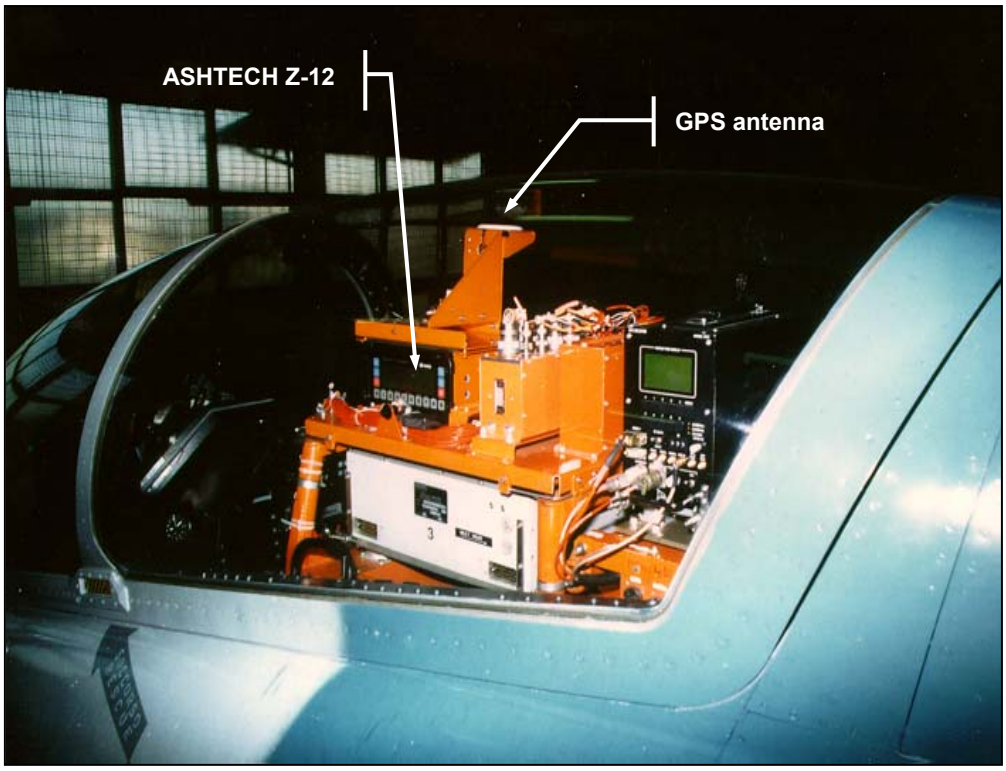


Figure 5-2: MB-339CD FTI and ASHTECH Receiver.

Another example of GPS installation, used in the Italian TORNADO-IDS Mid Life Update flight trials, is shown in Figure 5-3. Particularly, the GPS (ASHTECH Z-12) and the telemetry antennae are evidenced. The GPS antenna was located on the aircraft skin at about 1.5 m from the cockpit and a few decimetres from the telemetry antenna. The ASHTECH Z-12 receiver was installed in the avionics bay. In this case, the Electro-Magnetic Compatibility (EMC) and Interference (EMI) of the GPS/telemetry equipment (between each other and with the other on-board systems) had to be deeply verified before flight.

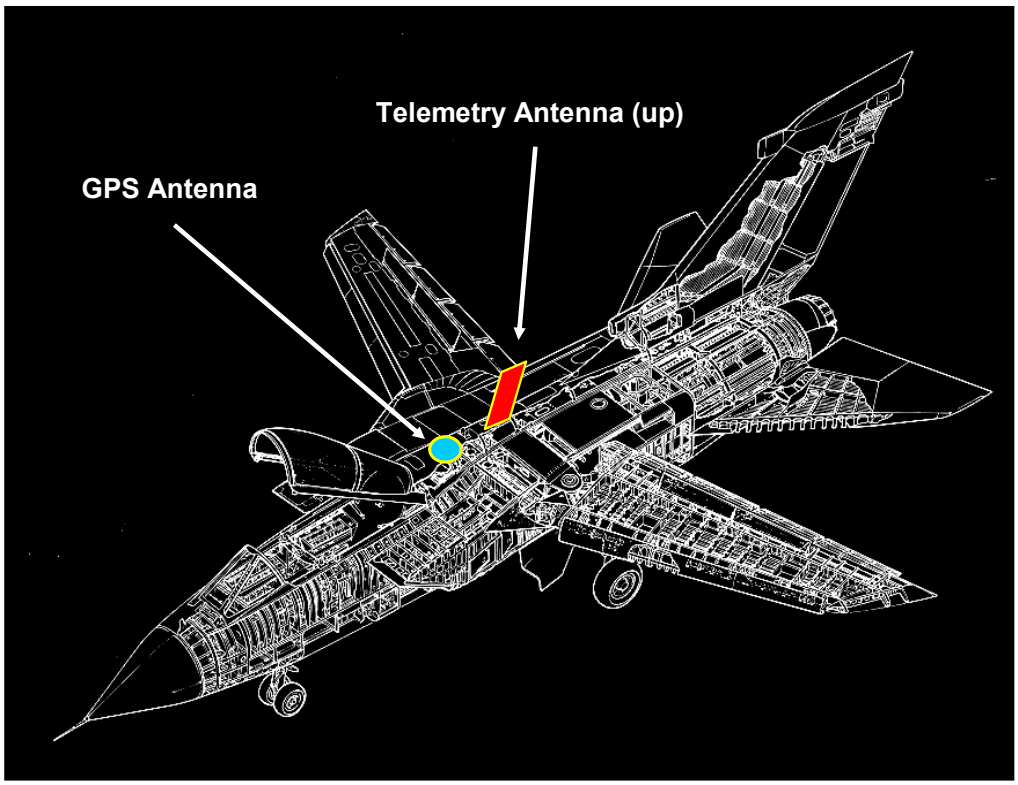


Figure 5-3: TORNADO-IDS GPS/Telemetry Antennae Installation.

Airborne GPS data recording was performed using the ASHTECH Z-12 internal memory, while the other aircraft data (INS position and attitude data, altitude data from radar altimeter and barometric altimeter, etc.) where recorded on a magnetic data recorder and other digital recording equipment available in the FTI.

One of the EF-2000 DA3 (Development Aircraft n° 3) installations is depicted in Figure 5-4, where the positions of the ASHTECH Z-12 receiver and telemetry/GPS antennae are shown. In this case, due to the greater distance between the GPS antenna and the telemetry antennae (located in a wing tip pod), there were much less concerns regarding the possible interferences between the telemetry transmitter and GPS receiver. However, also in this case, the EMC aspects of the installation were investigated before flight.

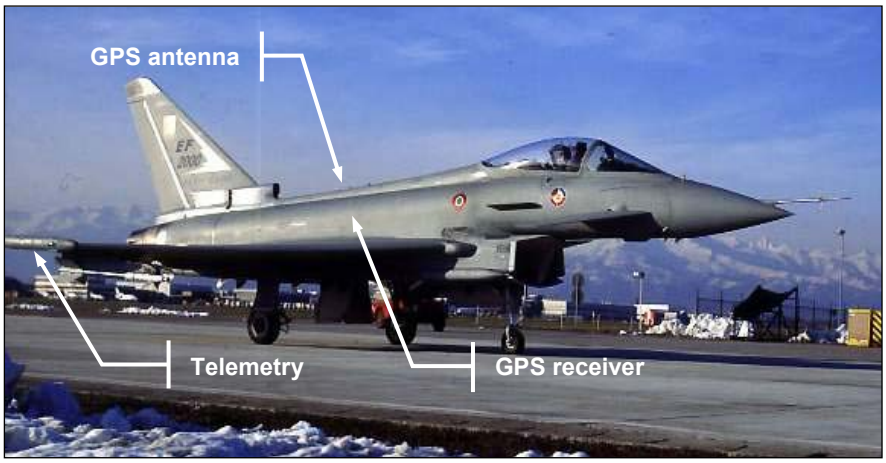


Figure 5-4: EF-2000 GPS/Telemetry Installation.

5.3 GPS SYSTEMS SET-UP

Before performing flight trials, it is important to select the set-up parameters of the on-board GPS receiver. These parameters can be programmed either by using the GPS receiver control panel units (e.g., ASHTECH Z-12 keyboard/display [1] on the receiver front panel) or by using a remote programming unit (e.g., a common PC in the case of TANS). Optimal parameters for flight test TSPI applications are the following:

- Data recording rate: 1 – 10 samples/sec;
- Masking angle: 10° (i.e., minimum satellite elevation over the horizon for multipath reduction);
- Minimum number of satellites for position computation: 3 only when using an external accurate altitude input (not with last available GPS altitude data) – 4 in all other cases[1];
- PDOP threshold (for position calculation): less than 5; and
- Minimum satellite signal SNR: 15 – 30 dB.

5.4 GPS DATA DOWNLOADING AND PROCESSING

As discussed in Chapter 3, GPS data downloading (from both the on-board and ground reference receivers) and differential processing can be performed on the ground (post-flight) for accurate aircraft trajectory reconstruction. In other cases (real-time DGPS implementations with datalink) differentially corrected data are computed on the ground by the reference station (one-way link) or in flight (bi-directional link), and recorded on-board the aircraft. In most practical implementations, however, the post-processing option is preferred both due to simplicity and high accuracy attainable with off-line carrier phase processing. In the following, some representative information is given about some of the ASHTECH post-flight data downloading and processing options. Particularly, the data transfer and differential processing procedures used with the ASHTECH Z-12 receivers (including a description of the relevant data files formats) is given in the following paragraphs, together with examples of dedicated

[1] Some GPS receivers incorporate an option that allows calculation of position using measurements from only 3 satellites (in this case, as tracking to the fourth satellite is lost, the last calculated height data is used to provide a position solution). In this case, obviously, the accuracy may degrade significantly in case of sudden aircraft altitude variations.

Flight Test Data Analysis (FTDA) software tools developed for the TORNADO-IDS and EF-2000 flight trials.

5.4.1 ASHTECH Data Downloading

Data downloading from the ASHTECH Z-12 receiver can be performed using the P-NAV software package, running on a common PC [1, 2]. Data are transferred to the PC through one of the available serial ports, using an RS-232-C standard interface.

The ASHTECH receiver can store data in different formats depending on the user requirements. Particularly, the receiver can:

- Store raw data (pseudorange and carrier phase) and position information (B-file in binary format), which can be corrected via software in post-processing using ephemeris data (E-file or ephemeris file) or in real-time;
- Store only raw (pseudorange and carrier phase) measurement data (B-file), which can be differentiated post-flight and ephemeris data (E-file). Position is calculated during data transfer; and
- Store position data in ASCII format (C-file) which can be corrected only in real-time.

During the TORNADO-IDS/EF-2000 trials, the first option was adopted. Therefore, the files gathered from the ASHTECH receiver, in binary format, are the B-files (code and carrier phases raw data, position calculated for each epoch and measurement quality parameters), the E-files (ephemeris parameters and satellite clock corrections) and, in ASCII format, the S-files (measurement site identifier, antenna height, meteorological information, and receiver type).

Differential processing (pseudorange) is carried out using a Post Processing Differentiation (PPDIFF) program, by simply inserting the coordinates of the reference station (previously determined by surveying). The computer then calculates the correction by simply subtracting true ranges from measured ranges. Corrections are then applied to the measurements of the on-board receiver (B-files).

Obviously, the externally inserted data have to be compatible with the B-file format, and therefore must include latitude, longitude, height (λ, ϕ, h) or cartesian coordinates (X, Y, Z) in WGS-84. The result of the differential processing carried out with the PPDIFF is a data file in ASCII format, conventionally named C-file (Figure 5-5).

```
Ashtech, Inc.      GPPS-2           Program:       PPDIFF       Version: 4.2
                   Fri Jul 09 08:28:06 1996 Differentially Corrected:Y
SITE    MM/DD/YY   HH:MM:SS           SVs   PDOP   LATITUDE          LONGITUDE
??84    07/08/96   11:32:32.00000      4    4.0    N 39.36166597  E 8.96212966
??84    07/08/96   11:32:33.00000      4    4.0    N 39.36166637  E 8.96212916
??84    07/08/96   11:32:34.00000      4    4.0    N 39.36166782  E 8.96213002
??84    07/08/96   11:32:35.00000      4    4.0    N 39.36166791  E 8.96212929
??84    07/08/96   11:32:36.00000      4    4.0    N 39.36166899  E 8.96212861
??84    07/08/96   11:32:37.00000      4    4.0    N 39.36166746  E 8.96212674
??84    07/08/96   11:32:38.00000      4    4.0    N 39.36166792  E 8.96212621
??84    07/08/96   11:32:39.00000      4    4.0    N 39.36166667  E 8.96212481
??84    07/08/96   11:32:40.00000      4    4.0    N 39.36166787  E 8.96212533
??84    07/08/96   11:32:41.00000      4    4.0    N 39.36166754  E 8.96212492
??84    07/08/96   11:32:42.00000      4    4.0    N 39.36166769  E 8.96212393
??84    07/08/96   11:32:43.00000      4    4.0    N 39.36166637  E 8.96212173
??84    07/08/96   11:32:44.00000      4    4.0    N 39.36166561  E 8.96212106
```

Figure 5-5: Example of C-File.

The C-files may contain data “holes” in correspondence of the following situations:

- When less than 4 satellites are visible; and
- When, with 4 satellites or more in view, the PDOP is too high.

In these cases the differential processing is normally not performed. Positioning data with an accuracy of 1 to 3 metres are obtained, using measurements from at least 4 satellites with a PDOP of 4.

5.4.2 Flight Test Data Analysis Software

The files obtained with the previously described procedures had to be modified in order to make them usable by the FTDA software. One of the first problems encountered in this phase was the transformation coordinates from WGS-84 (C-files) to ED-50 (European Datum 1950). Moreover, the coordinates of the reference station on the ground were given in ID-40 (Italian Datum 1940). Another transformation was then necessary from ID-40 to WGS-84 for applying differential corrections (using the PPDIFF).

Both the ED-50 and the ID-40 are referenced to an ellipsoid whose geometric characteristics were determined by Hayford in 1909. They are:

- Semi-major axis: a = 6378388 m; and
- Flatness: f = 1/297,

where the flatness (*f*) and the eccentricity (*e*) are related by: $e^2 = 2f - f^2$.

Adopting various orientations of this ellipsoid, different reference systems were obtained. Particularly, for the so called International Ellipsoid (i.e., the ED-50 ellipsoid) the Hayford system was used with the origin taken at the Greenwich meridian, while the Italian standard system (ID-40) was generated taking the origin at the Monte Mario meridian. Even if the ellipsoid parameters are in common (Hayford), it is

necessary to perform a coordinates transformation taking into account the different orientations, using the standard Helmert or standard/abridged Molodensky formulae [3].

The data analysis software could only process ED-50 coordinates. It was therefore necessary to use a software package for coordinates transformation to convert the geodetic coordinates (λ, ϕ and h) calculated by the PPDIFF in WGS-84 geodetic coordinates. Moreover, it was necessary to convert time data from GPS-Time to UTC. Starting with the files obtained by the different transformations, GPS data were processed with three different analysis software packages (SECDATA, DPLOT, MULTI) running on Unix platforms. These packages allowed determination (and plotting) of the aircraft trajectory during the flights (time, geodetic λ, ϕ and h) and production of other relevant diagrams (time histories, cross plots, etc.). The various processing steps are summarized in Figure 5-6.

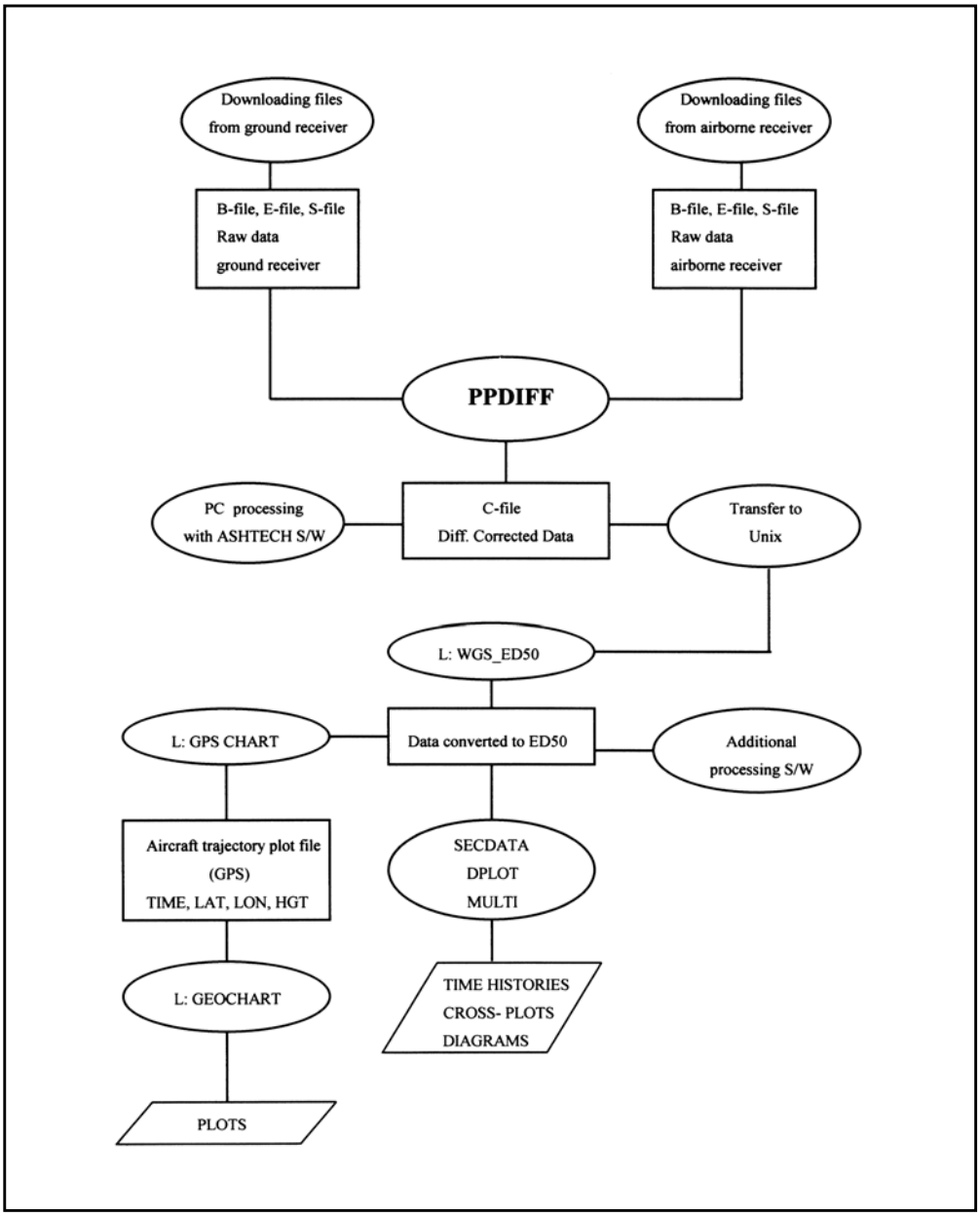


Figure 5-6: Data Processing Flow-Chart.

5.5 TELEMETRY LINK INSTALLATION

As already mentioned, a telemetry link is usually installed in order to allow exchange between the aircraft and the ground (flight test control station) of both voice communications and FTI/avionics data. As an example, in the case of the TORNADO-IDS/EF-2000 aircrafts, an L-band telemetry link was used with two antennae installed in the aircrafts: an upper antenna (distant a few decimetres from the GPS antenna) and a lower antenna. One of these antennas is shown in Figure 5-7.

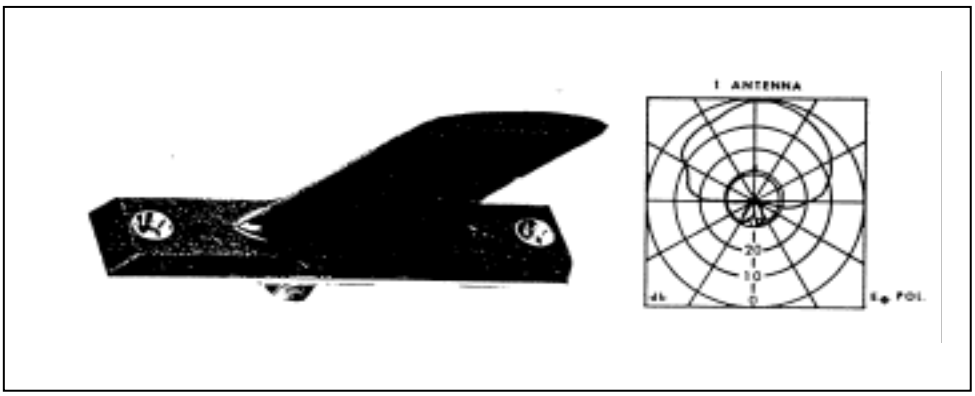


Figure 5-7: Telemetry Antenna (CHELTON 747-L).

The telemetry assigned frequencies are 1442.5 MHz, 1436 MHz, and 1460 MHz. The main lobe of the datalink carrier frequency has a main-lobe (600 – 700 KHz band) whose transmission level is 40 dBm (dB referred to 1 mW), and side-lobes with – 50 dBm levels with respect to the main-lobe. The power spectrum of the telemetry carrier signal at 1460 MHz received from the telemetry antenna directly connected to a spectrum analyser is shown in Figure 5-8.

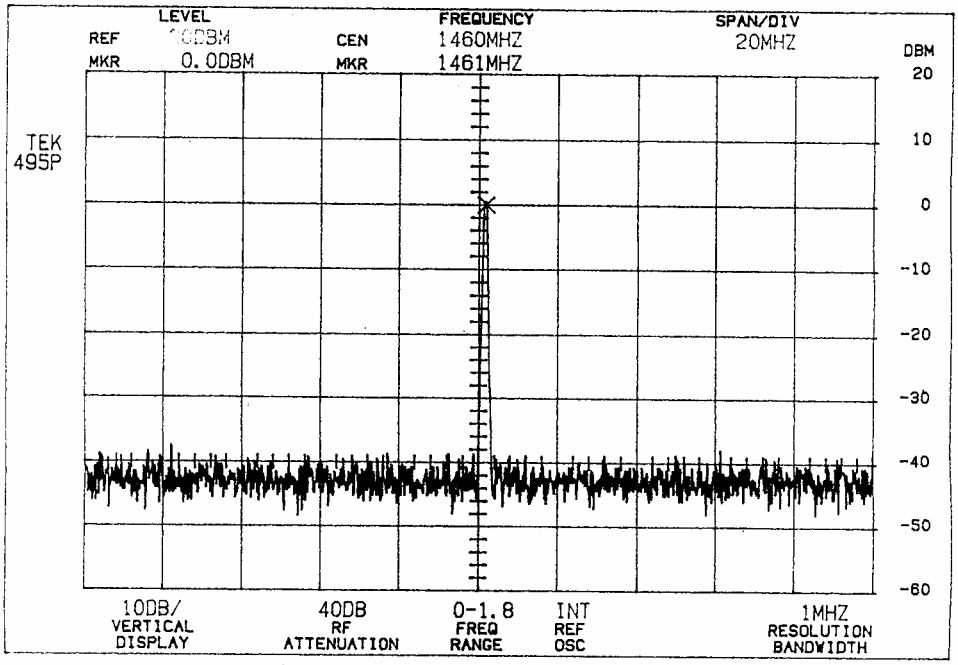


Figure 5-8: Power Spectrum of the 1460 MHz Telemetry Carrier.

A further spectrogram is shown in Figure 5-9, where the spectrum analyser reference level has been modified in order to detect spurious signals.

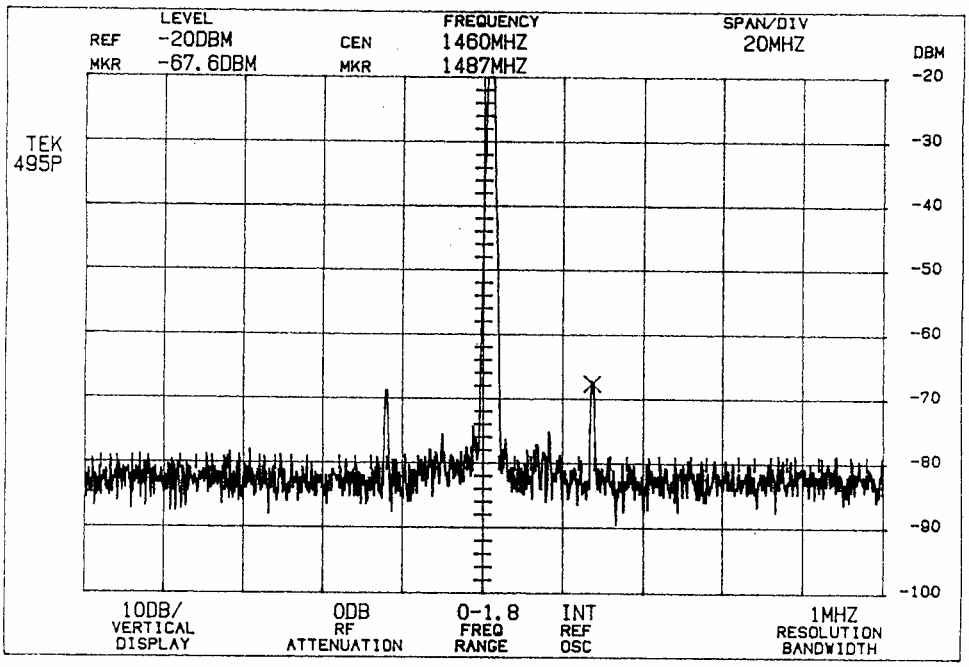


Figure 5-9: Power Spectrum of the 1460 MHz Telemetry Carrier (Enlarged).

5.6 DGPS REFERENCE STATION

As discussed in the Chapters 1 and 3, the architecture of the ground reference station may vary significantly depending on the applications. As an example, the DGPS Reference Station (RS) used for the TORNADO-IDS and EF-2000 ground and flight trials also used an ASHTECH receiver. In this case, a Choke Ring Antenna (CRA) mounted on a tripod was used for the ground DGPS-RS (Figure 5-10).

Figure 5-10: ASHTECH Choke Ring Antenna.

This type of antenna was chosen for the ground RS due to the marked reduction of multipath sensitivity documented in the literature [4].

The ASHTECH CRA is composed of vertical-aligned concentric rings centred about the antenna element, which are connected to the ground plane. These vertical rings shape the antenna pattern such that multipath signals incident on the antenna at the horizon and negative elevation angles are attenuated. The technical characteristics of the CRA are listed in Table 5-1.

Table 5-1: Technical Characteristics of the ASHTECH CRA

Standard Features

Billet Forged Choke Ring Antenna

- Billet aluminum construction, machined from a single piece of 6061-T6 aluminum
- Accepted IGS design
- Dorne & Margolin C146-10 element
- Conductive gaskets for antenna stability in humid conditions
- North marker for back-sighting alignment
- Gold alodine anti-oxidation coating
- Proprietary low-noise amplifier (LNA), 5 to 15 volt operation

Options

- Radomes
- Conical snow dome
- SCIGN short hemispherical radome
- Tripod
- Line amplifier
- Low-loss antenna cable

Choke Ring Antenna Specifications

Temperature
Operating –55°C to +65°C
Storage –55°C to +75°C

Humidity: 100%

Frequency
L1 1575.42 ± 10.23 MHz
L1 1227.60 ± 10.23 MHz

Polarization RHCP

Antenna Gain:
+5dBIC @ ZENITH
–4dBIC @ 5° ELEVATION

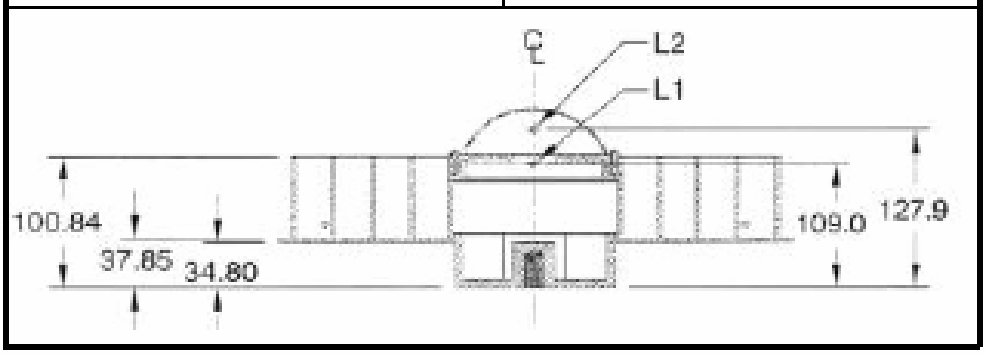
DC Power: 5–15V, 45mA TYP

LNA Gain L1: 38dB ± 3dB

LNA Gain L2: 38dB ± 3dB

Output: 50 OHM

Weight: 4.7 kg (10.5 lbs)



5.7 GROUND TEST ACTIVITIES

Generally, a preliminary ground session should be performed with the GPS receivers in order to preliminarily test the accuracy of the DGPS data and to gain a good level of confidence with differential techniques (data downloading and processing software tools) before performing actual flight trials. Furthermore, Electro Magnetic Compatibility (EMC) and Interference (EMI) ground tests have to be performed on the aircraft installations, in order to identify possible interferences between the aircraft avionics, the on-board GPS system and rest of the FTI. Some examples of ground test activities with DGPS are presented in the following paragraphs.

5.7.1 DGPS Confidence Ground Test

An example of a ground trial performed with two ASHTECH receivers is shown in Figure 5-11. The roving GPS receiver was installed on an electrically powered trolley and a second ASHTECH receiver was located in a surveyed site to provide data for differential corrections. The trolley covered a well-known route of about 3 km in the Turin International Airport (Caselle). The track was followed twice

(in opposite directions) along a road about 6.2 metres wide. After the trial, data stored into the internal memories of the two receivers were downloaded to a personal computer for differential processing and analysed as described in paragraph 5.4. Positioning data after differential processing (pseudorange) and post-processing noise reduction were very accurate. The stand-alone accuracy of the receiver was 22.4 m SEP (SA off) and well within the specifications. The results obtained with C/A code differential processing were also very encouraging with a position data accuracy of 3.1 m SEP.

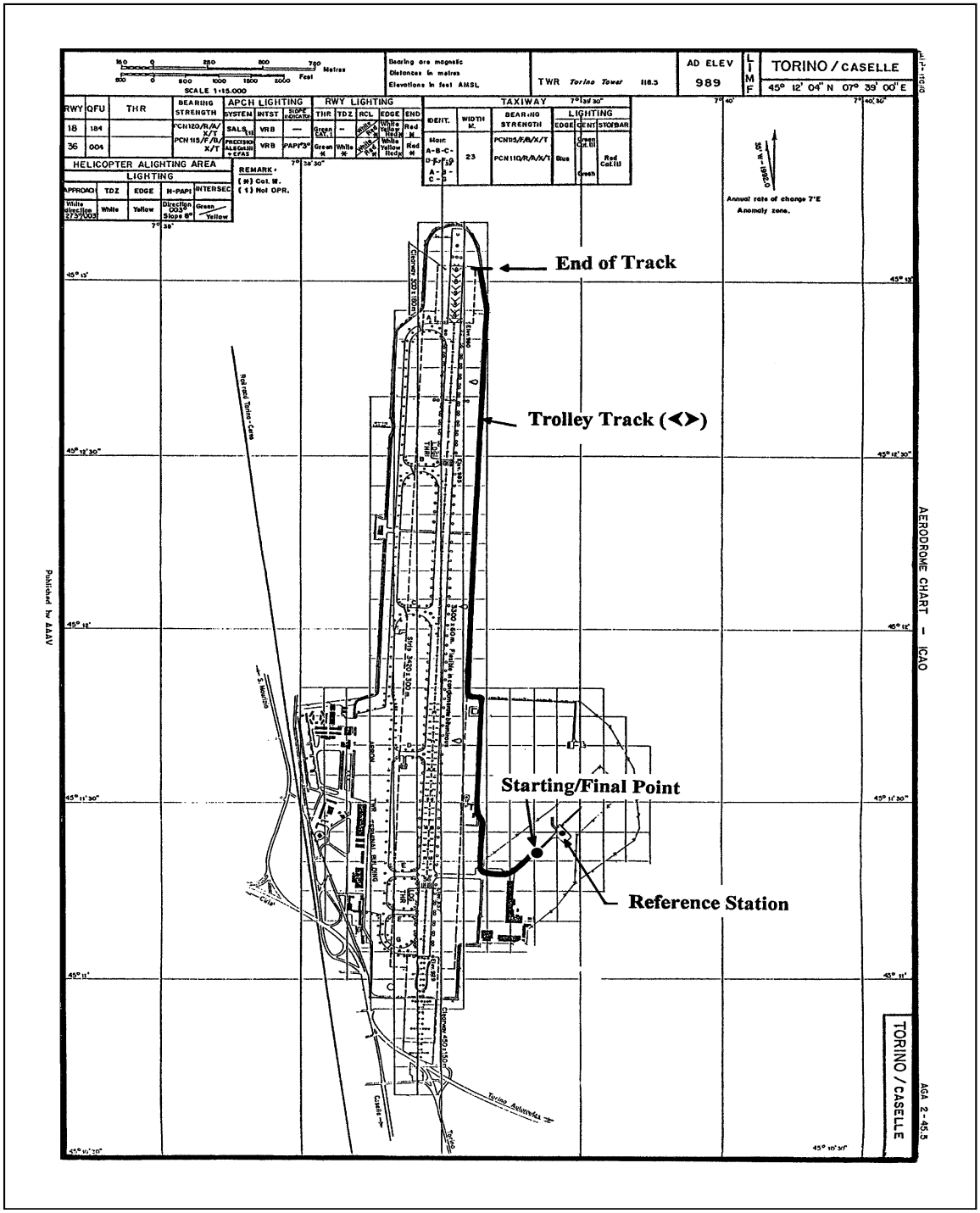


Figure 5-11: Aerodrome Chart with Reference Station and Trolley Track.

Even if this kind of ground tests can not be considered exhaustive for demonstrating the dynamic performance of the system, the activity permitted to gain confidence with differential techniques, essential for correctly planning and executing flight trials with DGPS.

5.7.2 EMC/EMI Ground Tests

Electro Magnetic Compatibility (EMC) and Interference (EMI) ground trials have to be performed with the GPS system installed in the aircraft, in order to identify possible mutual interferences between the aircraft standard avionics systems (communications, radio-navigation, identification, radar, etc.) and the newly installed DGPS/FTI. This kind of activity is routinely performed before initiating proper flight test campaigns, both for validating the installation of prototype/test avionics equipment and for verifying the FTI fit into the aircraft.

5.7.3 Telemetry/GPS Interference

A C/A code GPS receiver is designed to receive and process the GPS L1 signal at a nominal frequency of 1575.42 MHz and with a spectral band of 1.023 MHz. Due to the characteristics of the Code Division Multiple Access (CDMA) transmission technique, which spreads the spectrum of the signal over a large band reducing its level, the signal received on the earth has a level in the order of –157 dBm that is close to the background noise level. Therefore, it is worthwhile to assume that the telemetry signals (frequently transmitted in L-band or with significant harmonic content in that band) from the aircraft, would be at a level significantly higher than the received GPS signal. In order to investigate the effects of the telemetry signals on GPS satellites acquisition, some ground trials have to be performed.

In Annex B we reported a case study relative to the interference ground tests performed on the TORNADO-IDS installation.

5.8 REFERENCES

[1] ASHTECH Inc. (2001). “ASHTECH Z-12 Receiver”. Technical Specification Leaflet.

[2] ASHTECH Inc. (2001). “ASHTECH P-NAV User’s Manual”. Document Number 756805. Sunnyvale CA (USA).

[3] Defence Mapping Agency. (1991). “Datums, Ellipsoids, Grids, and Grid Reference Systems”. DMA TM 8358.1. Fairfax (VA).

[4] Ogonda, G.O. (2003). “Setting-up of GPS Reference Stations and Investigating the Effects of Antenna Radome”. PhD Thesis. University of Stuttgart – Institute of Navigation.