ANTENNA PRECISE POINTING CALIBRATION USING LOW COST DGPS

Pedro Rubio, Jesus Alvarez
AIRBUS DEFENCE & SPACE Flight Test

ABSTRACT

Pan&Tilt directional antennas are present in every Airspace Test Center. They are used to receive telemetry data from the target in test (usually a rocket or an aircraft).
Required telemetry range can be usually around 200nm which leaves no option but to use directional antennas (parabolic among others).
The use of directional antennas greatly enhances the telemetry range by a factor of 1000. But it does it at a cost: directional accuracy.
This kind of antenna has a narrow radiation pattern with its nominal gain at the center of the antenna dish. The main beam of the radiation pattern can be as narrow as 1.8 degrees (3db) in a C Band 2.4m parabolic antenna.
An antenna has to be pointing its radiation pattern main lobe to the flying target with an error of less than the main lobe width in order not to degrade reception.
A method has been implemented to properly calibrate the mechanical pointing vector to overlap with the radiation pattern main lobe.
The calibration method presented in this paper allows a very precise calibration that can be performed locally with the aid of DGPS, RF Beacon, RF Spectrum Analyzer and software to manage the whole process.
Main advantages:

- High precision. Adequate for C Band narrow radiation patterns
- Low cost
- Highly integrated procedure thanks to developed software
- No need of far satellites or the sun.

Alternative application:

- 3D Radiation pattern determination

Key words: dgps, rtk, pointing, antenna, calibration, radiation pattern, telemetry

INTRODUCTION

A Flight Test Ground Station (GS onwards) or Telemetry Station provides support to Test Flights by receiving real time telemetry from the Aircraft and forwarding engineers feedback back to the Aircraft Crew.
Telemetry transmission to ground from flying vehicles is a key factor in the testing phase of any new development. With every new prototype more data is acquired and sent to ground for real time analysis. As the data rate increases, a higher frequency band is preferred for the air channel.
Due to the highly crowded radioelectric environment and the higher bandwidth requirements, it was approved a new worldwide official band for telemetry transmissions: C Band from 5090 to 5250.
Flight tests centers used to have parabolic antennas for telemetry reception up to 200 nm.
Standard parabolic antenna in a ground station ranges from 1.5m to 2.4m. At that frequency and diameter, they tend to have a very narrow beam thus imposing an important restriction to the pointing accuracy.
In the following image can be seen the narrow main lobe.

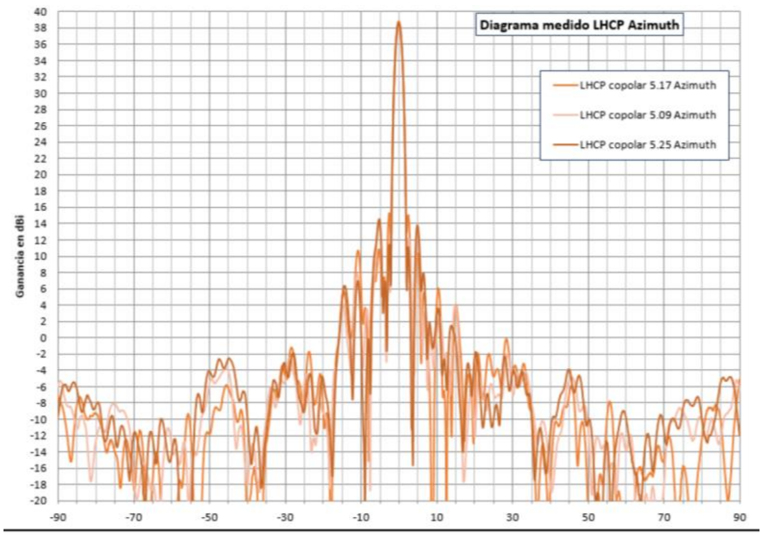

Figure 1

PARABOLIC ANTENNA POINTING METHODS

Parabolic (or any directional antenna) needs to be pointed at its target in order to attain its highest range.
What really happens is that the main lobe of the radiation pattern is pointed to the transmitter antenna in the aircraft providing the highest peak gain.
There are several methods to point an antenna to a moving target:

- GPS Tracking
- Autotracking

These methods have advantages and disadvantages.

For example, GPS method allows for a lower price and lower complexity antenna but needs an external calculation and a very precise calibration.

1 AUTOTRACKING

Autotracking method needs no external information. It relays on the measured incoming power at different offsets in order to guess its own pointing error. It requires a complex/expensive feed design that allows antenna ACU to calculate the error vector based on RF power analysis

2 GPS TRACKING

Using this method requires having a valid GPS position of the tracked vehicle at all time.
Position can be retrieved using its own telemetry data or by external methods like ADSB, Flight Radar, etc.
Based on the GPS position of the aircraft and the ground antenna, Azimuth and Elevation of the antenna can be calculated easily.
Any antenna can be operated using this method with the advantage of price and simplicity.
However the simpler and lower budget comes at a cost, the antenna has to be very precisely calibrated in order to perform well.

MISALIGNMENT EFFECT

Telemetry centers are already using C Band with Parabolic dish diameter from 1.5 to 2.4m.
Radiation pattern of that setup could be very similar to the one shown below.

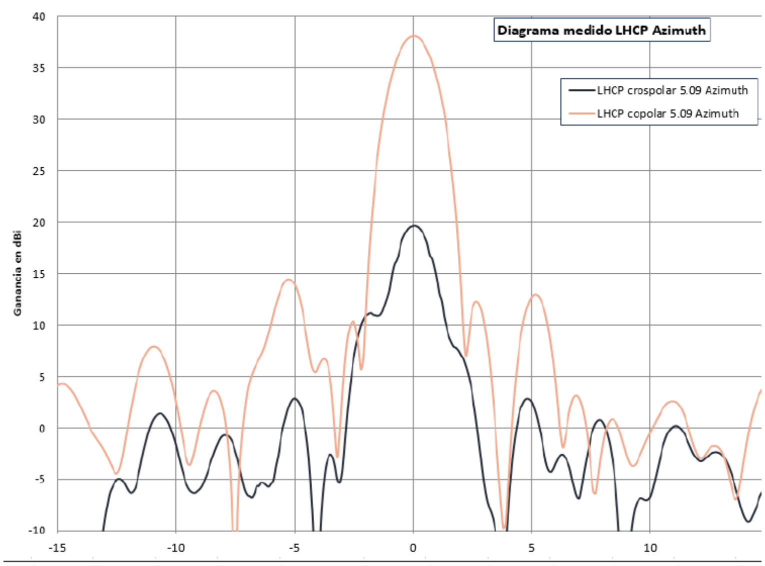

Figure 2

Notice the narrow main beam of the radiation pattern in azimuth axis.
The 3db gain bandwidth is only ~1.6 (-0.8 to 0.8) deg wide. This imposes a big constraint in the maximum admissible pointing error.

In order to understand how critical the pointing error is, just remember: 6db loss means half the range.

ANTENNA CALIBRATION OVERVIEW

There are basically two calibration parameters associated to a Pan-Tilt Antenna.

- Horizontality of Pedestal Plane
- True North

1 CALIBRATION PARAMETERS OVERVIEW

1.1 Horizontality of Pedestal Plane

Horizontality of the antenna pedestal is mainly done the moment the antenna is installed by physical means.
Basically the antenna base has to be as perfectly horizontal as possible in order to provide precise elevation position at any azimuth.
Any offset in the base plane relative to the horizontal plane (perpendicular to gravity vector) would translate in a variable elevation error depending on the azimuth position.

Figure 3

It can happen that, due to bad installation or aging, the antenna pedestal no longer is perfectly horizontal. If it happens, it can be fixed with a physical calibration or with a much easier Horizontal-plane offset software compensation.
Due to the difficulty of a physical calibration, effects of horizontality errors are often ignored unless they are very noticeable.

1.2 True North

Azimuth offset calibration to align 0deg to true north is one of the most critical configurations of a pan&tilt antenna.
Ensuring that true north orientation matches with 0deg software azimuth is critical.

As we have seen previously, typical desired maximum error should not exceed 0.5deg

2 LEGACY CALIBRATION METHOD

In this section, it will be shown how a pan&tilt antenna is usually calibrated.

2.1 Horizontality of Pedestal Plane

It is calibrated at installation time by physical means and qualified personnel.
Antenna pedestal provides some kind of adjustment by using thin metal plates or any other means.
Horizontality is measured using a precision digital level.
Operator has to follow a manual measure-correct method for each X/Y axis until pedestal is completely horizontal.

2.2 True North

Antenna horizontal calibration must be done previous to true north calibration.
True north calibration is usually done by tracking sun position or by tracking a well-known satellite.
The process needs to know the tracked item position.
Using a RF power meter, the antenna is pointed manually or automatically (if autotracking is available) precisely to the item by maximizing the apparent input power in the analyzer.
Once the antenna is finely positioned, actual AZ and ELEVATION is obtained by knowing antenna position and tracked item position.
This method requires good sun visibility for a first broad positioning and can only calibrate one sector.

PROPOSED CALIBRATION METHOD

Airbus DS has developed a method to calibrate all the parameters of a pan&tilt antenna with a single procedure.
The aim is to automatize and minimize manual work in order to limit errors and to bust productivity.
The proposed calibration method is based upon one principle:

Compare the indicated AZ and ELEV from uncalibrated ACU to the calculated AZ/ELEV by DGPS Baseline

---

The proposed method does not rely on external satellites or the sun and thus it is not exposed to shortages or weather problems.
The calibration will be based on opensource software for DGPS postprocessing and cheap L1 GPS hardware.

1 BENEFITS

- High precision
- One measurement – Two calibrations
- Low cost
- High availability

2 BOM (Bill Of Materials)

RF Generator + Omni Antenna (C Band)

An RF transmitter is needed in order to transmit a beacon signal from designated points around the antenna site.
It has to be able to transmit in the used band with at least 100mW and a isotropic radiation pattern.

C Band 100mW TX

Figure 4

Antenna C Band Isotrop

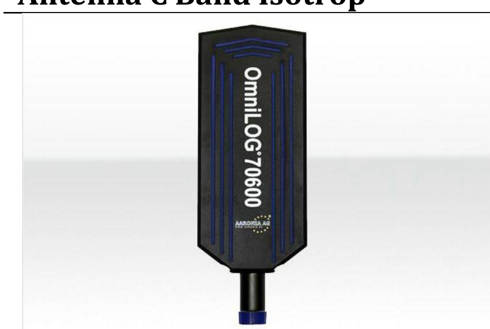

Figure 5

GPS L1 with Phase Recording

A GPS unit capable of phase observation recording is needed. It has been used a L1 GPS/GLONASS inexpensive unit with integrated Intel Edison processor.

This module allows for a very small footprint with no need of additional equipment.

Figure 6

Spectrum Analyzer

Received power is measured with a spectrum analyzer in wattmeter or power channel meter mode.

Figure 7

Analysis Software

Airbus DS has developed software for data analysis.

It allows inputting GPS observations at different locations along with its measured azimuth and elevation. It will post process GPS observations to calculate precise DGPS positions of antenna and rest of locations. Once the software has precise location it can calculate the baselines and actual elevation and azimuth at those points.

The final output of the software is a correction horizontal plane and azimuth correction number.

3 FUNDAMENTALS OF DGPS

DGPS (Differential GPS) is a method to calculate precise GPS receiver coordinates by applying corrections from a nearby GPS receiver with well-known coordinates.

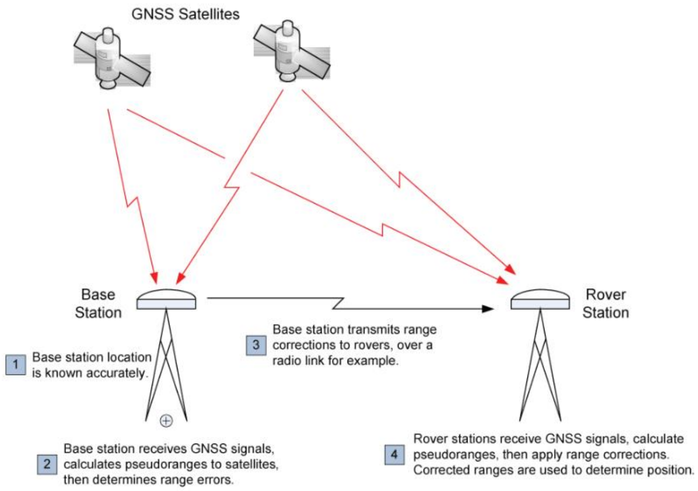

Figure 8

Differential GPS is based on the fact that similar errors (ionosphere, etc) affect similarly to receivers in the same zone. Errors are strongly correlated in gps.
This method needs two GPS receivers capable of gps phase measurement.
One receiver will be called BASE and will be placed in a known location. It will not move and will provide correction to the other GPS receiver (called ROVER).
The ROVER receiver will be the one that actually measures the positions of the interest points.
In the correction process, called RTK, the RTK Software will compare the BASE known/imposed position to the one calculated and will derive corrections to be applied to the ROVER.
The correction process can be done in real time or offline in post-process.
RTK methods were usually only used with high-grade topography L1/L2 GPS receivers. Using this high quality equipment allows a wide baseline distance of up to hundreds of kilometers and very quick convergence times in the RTK Integer Ambiguity resolution.
Nowadays, with the increasing availability of satellites constellations, L1-only GPS receivers obtain very good results for a number of applications.

L1-only GNSS

L1 GNSS Receivers have increased their popularity in the last years. They have increased the number of tracked constellations (the more satellites available the better the solution can be) allowing longer baselines and quicker times-to-fix.
More satellites and better RTK algorithms means that L1 GNSS receivers can be a good alternative for many applications while maintaining a very low cost.

RTK Software

Opensource RTKLIB suite has been selected as the processing software.
It features:

- Real time and post-processing solution
- L1/L2/L5 Bands

- Multiconstellation
- Forward/Backward solution
- Multiple Input file format
- AR Engine tuned for L1-only receivers
- Opensource SW. Improvements and changes possible.

4 COMPLETE PROCEDURE

The complete procedure has two main parts, the field data gathering and the office post-processing.
It has been chosen RTK post-processing instead of real time as it is less complex in hardware and provides more benefits like the combination of forward and backward solution.

Field data gathering

The parabolic antenna will be located precisely with the aid of DGPS location.
Four points around the antenna will be chosen to:

- transmit a beacon signal
- measure indicated AZ/ELEV by ACU
- Calculate actual AZ/ELEV in post-process.

The pattern for the field locations will be similar to next figure:

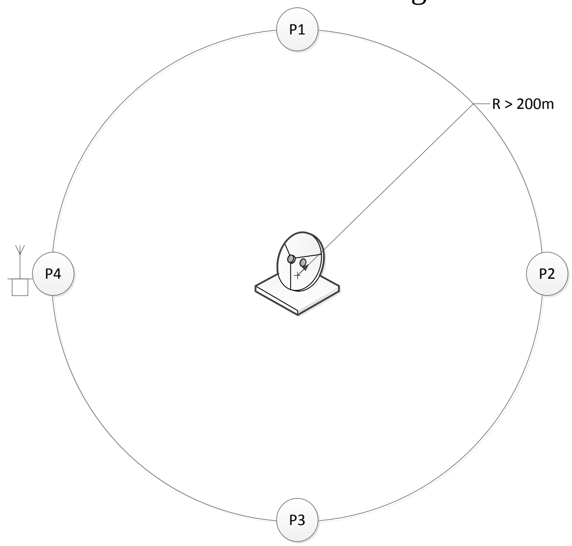

Figure 9

Radius shall be greater than the Far Field boundary.
For 5.150 Ghz and a 2.4m antenna, Far field begins at 198m.

The simplified procedure can be listed as follows:

A. Setup BASE in a known position and assign a fixed position LLA. Start recording
B. Setup ROVER. Start Recording.
C. At Antenna location.
    - Trigger ROVER Event (to record time)
    - Leave recording 5 minutes
D. At perimeter points

- Trigger ROVER Event
- Leave recording 5 minutes
- Transmit beacon
- Operate Antenna to attain maximum input power using Watt meter of Spectrum Analizer.
- Annotate Indicated AZ/ELEV reported by ACU

E. Stop BASE and ROVER Recording

Office post-processing

Post-processing software will calculate precise locations for antenna and perimeter points.
Vectors from antenna to every perimeter point will provide the actual AZ/ELEV that the antenna should have based on DGPS processed locations.
Based on this information, the software will calculate the offset plane and the true north azimuth offset to be applied to the Antenna ACU.

CONCLUSIONS

The calibration method described in this paper allows for a very precise antenna calibration while not relying in any external satellite.
It uses advanced DGPS techniques with custom tailored software to provide a quick and robust calibration algorithm.
The proposed method provides a plane calibration on top of the usual azimuth north calibration.
Horizontal plane calibration increases the degree of pointing accuracy by adjusting the elevation offset dynamically as the azimuth changes.
Methodology described in this paper can be evolved to create complete radiation patterns by automatizing antenna movement with spectrum analyzer zerospan sweep.