Ground Check of GNSS Antennas on Aircraft

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BIOGRAPHY (IES)

Study of Electrical Engineering at the Technische Universität Braunschweig, Germany
Received Diploma in Electrical Engineering in 1983.
From 1983 to 1993:
Work as a research and design engineer with "Magnetbahn GmbH" in Braunschweig for propulsion and safety components of Mag-Lev trains.
Since August 1994:
Work at the Competence Center Flight Inspection Systems of the Aerodata AG in Braunschweig, Germany.
Main fields are:
System engineering, Compliance verification for EASA projects, EMI, Radio, Telemetry, AFIS hardware, GBAS, Safety related issues ,Airworthiness certification, Customer support

Holder of a Private Pilot license since 40 years.

ABSTRACT

After installation of new Flight Inspection antennas on aircraft, they should be tested on ground according to their typical technical data.

Typical steps for normal RX/TX antennas are checks of:

- Bonding
- Cable loss
- VSWR (reflected energy versus frequency with reference to the nominal impedance)
- Frequency depending signal response

On active antennas like GNSS/GPS/GLONASS/Terrastar or ADF, the VSWR check is not possible because an active component like an internal amplifier (made for signal flow in one direction only) will not respond to reflection measurements (signal flow in two directions).
This paper shows practical solutions to validate GNSS antenna performance after installation and a handy way to check antenna performance as a maintenance task. Without these test procedures trouble shooting on GNSS antennas and wiring is only possible by changing boxes and the hope, that the failure disappears.
With the test installation described, further measurements on aircraft GNSS antennas can be performed to identify overload situations due to strong in-band and out-of-band transmission from the own aircraft or high power ground stations (e.g. RADAR, UMTS/LTE) resulting in loss of GNSS signals.
Additionally, a faulty (interference) situation on an airborne multiple-antenna installation found in practice, resulting in temporary loss of GNSS in flight, is shown.
Selection of antenna types with reference to their system is discussed.

INTRODUCTION

Why should antennas be checked after installation before first flights?

After installation of new Flight Inspection antennas on aircraft, they should be tested on ground according to their technical data. This will save unnecessary flights if they are not fully serviceable and eases trouble shooting in initial system tests.
Typically steps for standard FIS RX/TX antennas are:

- Bonding

- Cable loss
- VSWR (reflected energy versus frequency with reference to the nominal impedance)
- Frequency depending signal response

On active antennas like GNSS/GPS/GLONASS/Terrastar or ADF the VSWR check is not possible, because an active component like an internal amplifier (made for signal flow in one direction only) will not respond to reflection measurements (signal flow in two directions). Alternative test procedures had to be developed.

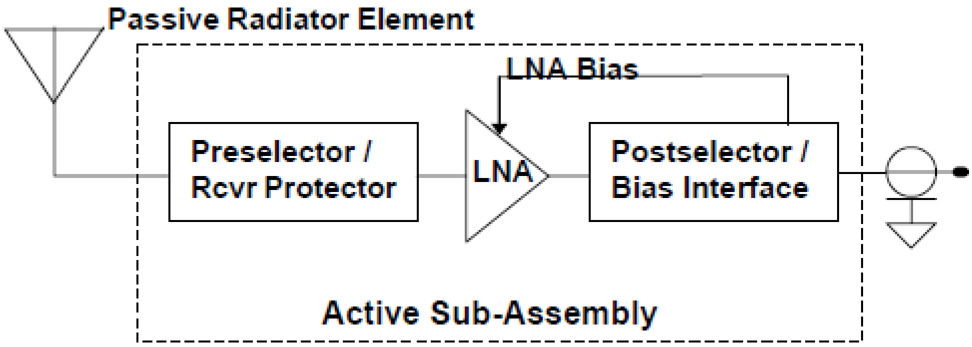

Figure 1: Typical Block diagram of an active GNSS antenna

GNSS FREQUENCIES

GNSS services use a wide variety of frequencies in the L-Band from 1 to 2 GHz. Each service has a dedicated center frequency and a dedicated bandwidth (typ. Range between +/- 1 and +/- 10 MHz).

Service	Frequency
L2 GPS	1227.60 MHz
GLONASS L2 (Lo)	1248 MHz
L1 GPS	1575.42 MHz
GLONASS L1 (Hi)	1607.5 MHz
L5 GPS	1176.45 MHz
E1, E2 Galileo	1575.42 MHz
L5 Galileo	1191.795 MHz
E6 Galileo	1278.75 MHz

Table 1: Typical GNSS frequencies in Europe

Service	Frequency
E5, E5a, E5b Galileo	1164 – 1219 MHz
L5 IRNSS (India)	1176.45 MHz
B2 Compass/Beidou	1207.14 MHz
L2 GLONASS	1252.50 MHz
B3 Compass/Beidou	1268.52 MHz
OMNISTAR	1542.50 MHz
L6 Galileo	1542.50 MHz
B1 Compass/Beidou	1561.098 MHz
L1 IRNSS	1575.42

Table 2: Other GNSS frequencies

SYSTEM BLOCK DIAGRAM

The block diagram shows the set up to check the antenna under test “RX-Antenna on aircraft” in a complete loop including DC-power feeder and transmitted RF-signals onto the antenna. Antenna may be mechanically installed and the aircraft wiring (as installed) is part of the test set up.

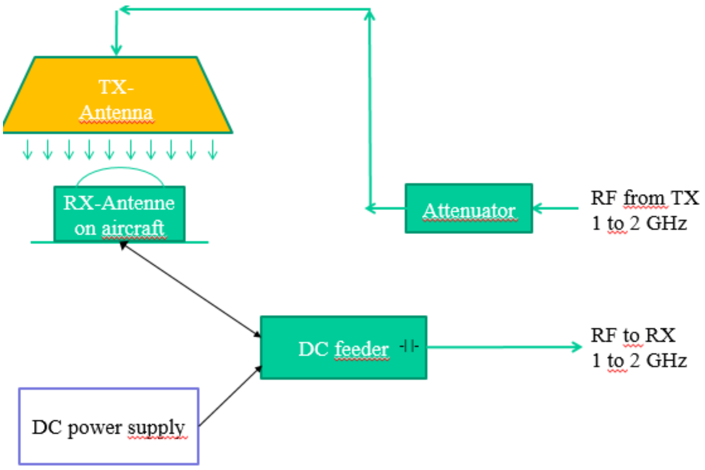

Figure 2: System Block diagram (simplified)

RX and TX can be connected to any transmitter and receiver. A very easy way of presenting the data is the use of a spectrum analyzer with integrated tracking generator.
This test set up is not based on reflection measurements. Signal flow is in forward direction only.
Active antennas need an external power supply.

REFERENCE ANTENNA FOR SYSTEM CHECK

A standard, well known and serviceable GNSS antenna is used as reference and for system checks before each new test installation. Plots are expected to be similar within 1 or 2 dB range, depending on the quality of cables.

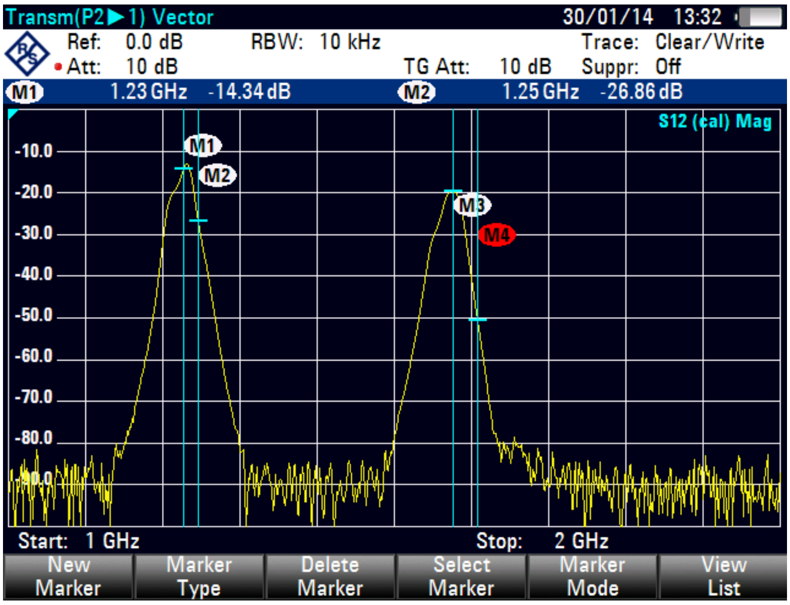

Figure 3: Reference antenna standard plot.
Marker setting of M3 = 1.575 GHz and M1 = 1.227 GHz

This reference antenna is perfect for GPS L1, L2 but <u>NOT</u> for GLONASS Hi and Lo band

PLOTS OF TYPICAL GNSS ANTENNAS

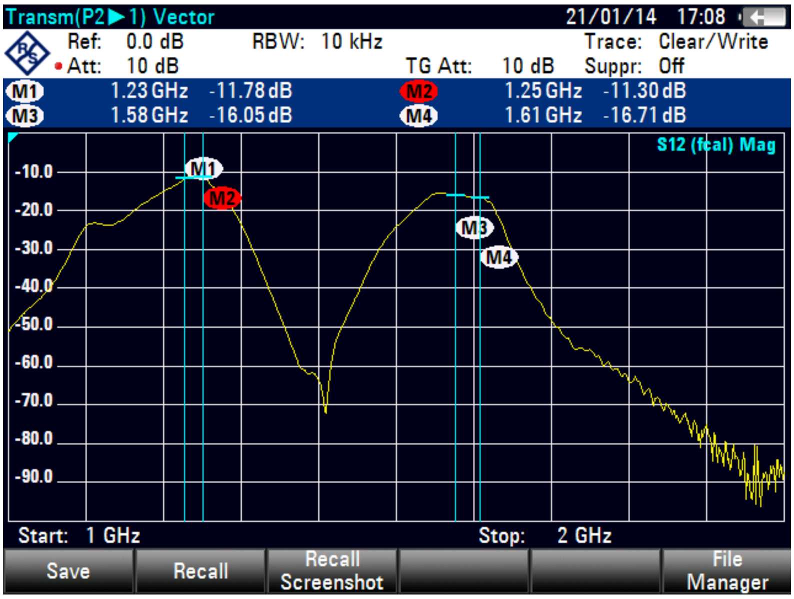

Figure 4: Broadband Antenna labelled "OMNISTAR"

This wide-band antenna is perfect for GPS L1, L2 and for GLONASS Hi and Lo band as well as other services. It does not reject out-of-band signals in a proper way.

Figure 5: Passive Antenna

This passive antenna was designed for L1 only. Signal is approx. 30 dB lower compared to amplified antennas

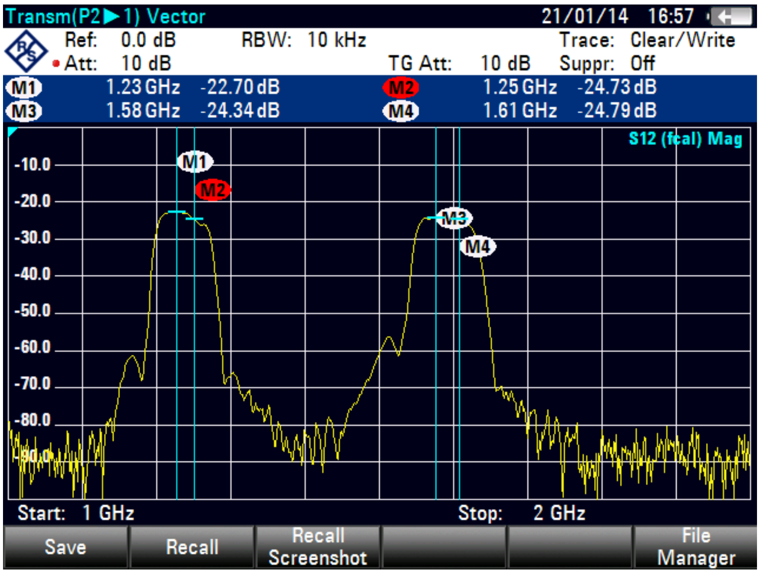

Figure 6: Typical DGPS Ground Station Antenna


Figure 7: Test set up for a DGPS Ground Station Antenna

This antenna is perfect for GPS L1, L2 and GLONASS Hi and Lo band. The shape of the RF filters look perfect.

ACCURACY, REPRODUCIBILITY AND RF FIELD ASPECTS

The test set up is not calibrated for absolute antenna gain measurements. With reference to a well-known standard antenna only comparative measurements are performed.
All data of tests on different antennas with reference to P/N and installations details (wiring etc.) are recorded and published for future reference in an operation manual for the test equipment (company confidential).
With this reference data it is very easy to identify an antenna which does not behave as expected resp. “normal”.

While developing the test set up procedures several analytical and practical tests regarding far and near field aspects have been investigated. This includes required mechanical positioning accuracy of the TX antenna, polarization effects (RHC / linear) and effects on the RX antenna caused by the close distance to the TX antenna. It was found, that all of these aspects have only minor effect on comparison measurements. After several years of experience the reproducibility of measured data is always within a range of single dBs.

SELECTION OF GNSS ANTENNAS FOR INSTALLATION ON AIRCRAFT

GNSS Antennas should be selected to match:

- Required service frequencies
- Required amplifier gain in combination with cable loss
- Avoid overload by out-of-band high power signals
- In Flight-Inspection operation be similar to popular /standard antennas of aircraft typically using the different GNSS services
- Mechanically and environmental aircraft specifications
- GNSS Antennas should always be installed outside the fuselage. Any installation inside, e.g. on a dashboard, will shade approx.. half of the hemisphere and degrade use of GNSS receivers strongly.

It is good practice to select the antenna with the smallest frequency band for reliable services requirements and a “wide-band-antenna” to identify interference sources.

At some point, the active antenna system becomes overloaded, showing

- Non-linear effects
- Intermodulation effects
- Irreversible damage of components. Burnout criteria of DO-301 is +20 dBm at pre-amp input, resulting in approx.. +50 dBm to +60 dBm at antenna output connector.

No saturation or distortion effects were observed within an output power level of max. 0 dBm (at antenna connector) with all antennas under test.
A detailed IP3-(Intercept-point) Intermodulation test has not been performed until now.

TROUBLE SHOOTING WITH THE TEST SET UP

A customer came to our maintenance facilities and reported intermittent unusable GPS in several GNSS systems in the aircraft in flight. The test set up was installed and most GNSS antennas showed normal behavior.
At some point an unusual additional, slightly out-of-band-signal showed up, identified as a transmitted signal, unstable in frequency. It disappeared synchronous to one of the four GPS systems powered down.
Characterization of the failure condition:

- A single failure interfered all systems at the same time
- This is similar to an interference of the received GNSS spectrum from outside onto the aircraft. But this is typically a geo-local problem which disappears while aircraft moves away
- In this case a local occurrence could not be verified
- Is the interference source on board of the own aircraft?

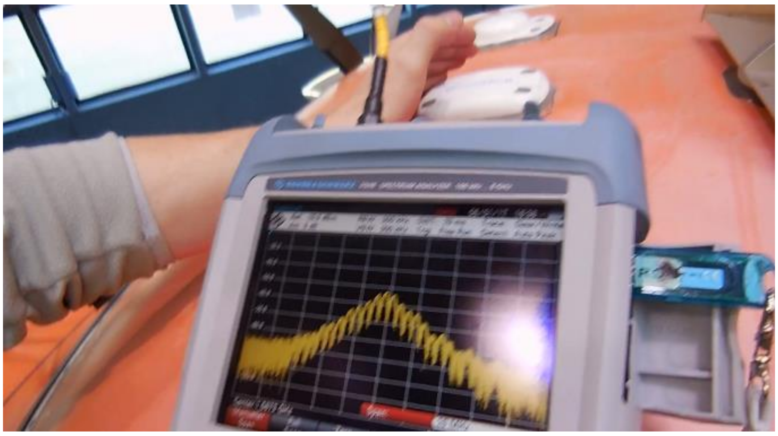

Figure 8: Test set up to identify source of transmitted frequency

The spectrum analyzer could be located close to the suspected antennas. The free floating oscillator could be de-tuned by the additional capacity of the hand. If the hand comes closer, the oscillators reduces the frequency by approx.. 2 MHz. It is expected, that this frequency also strongly depends on temperature, humidity and other environmental conditions in flight.

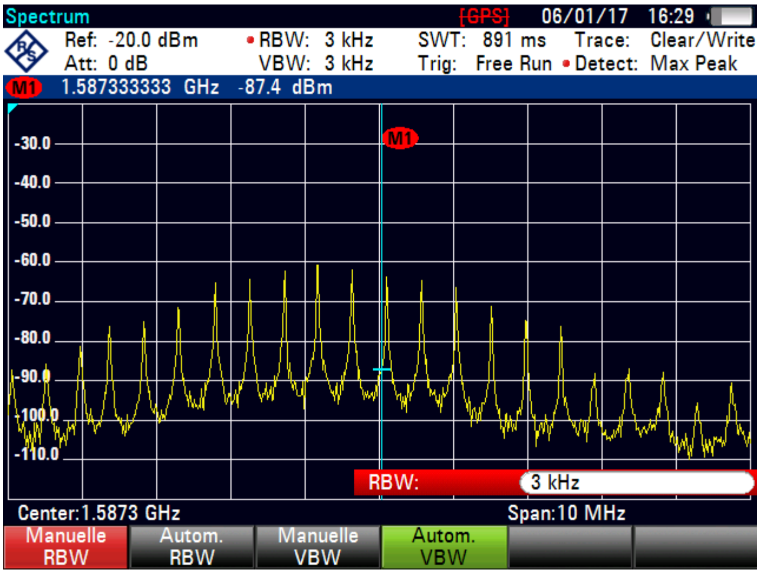

Figure 9: Screen shot of the free floating oscillator signal

The free oscillating GPS antenna amplifier had an unstable center frequency of 1.5873 MHz, close to L1

INVESTIGATING FREE OSCILLATIONS OF AN ANTENNA AMPLIFIER IN THE LABORATORY

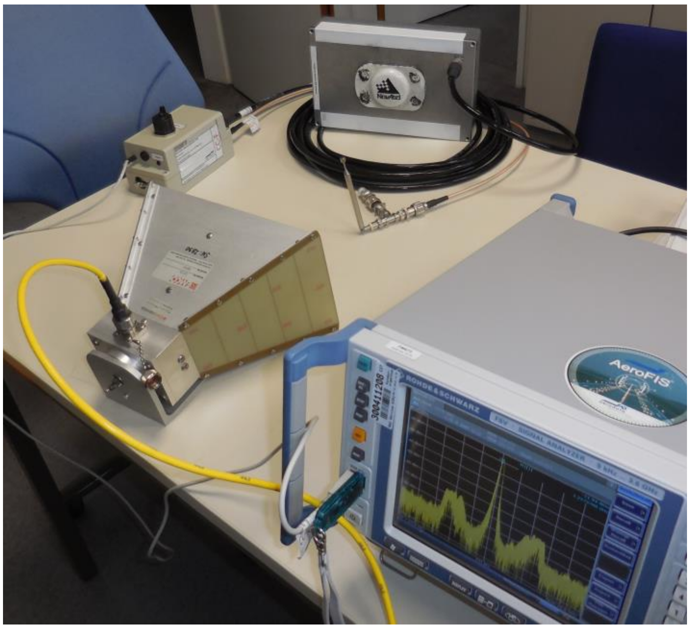

Figure 10: Test set up to produce oscillations by an open feed-back-loop

An oscillator was built with an amplified GPS RX antenna connected to a broadband telescopic TX antenna with a loop through-the-air, monitored by a spectrum analyzer. Both antennas plus the amplifier formed an oscillator. Internal GPS antenna filters are in the loop.
The idea was to find out, whether an incorrect shield installation of the antenna wiring could cause the system to oscillate.
No evidence could be found, that a single shield failure inside a metallic fuselage would cause the oscillation as shown on the aircraft.

REGULATIONS OF GNSS ANTENNA ON AIRCRAFT

The main TSO definitions are found in TSO-C190 e.g. for current GPS based FMS or GPWS systems.
The technical specification is published in detail in RTCA-DO-301. This DO-301 does not cover other services then L1 for GPS and Galileo.
It specifies in detail the shape of the RF filtering.

Department of Transportation
Federal Aviation Administration
Aircraft Certification Service
Washington, D.C.

TSO-C190

Effective
Date: 3//30/07

Technical Standard Order

Subject: Active Airborne Global Navigation Satellite System (GNSS) Antenna

3. **REQUIREMENTS.** New models of active GNSS antennas identified and manufactured on or after the effective date of this TSO must meet the MPS qualification and documentation requirements for active antennas in RTCA Inc. document RTCA/DO-301, *Minimum Operational*

c. **Functional Qualification.** Demonstrate the required performance under the test conditions in RTCA/DO-301, Section 2.4.

Figure 11: TSO-C190

Minimum Operational Performance Standards (MOPS) for Global Navigation Satellite System (GNSS) Airborne Active Antenna Equipment for theL1 Frequency Band

This document contains minimum operational performance standards (MOPS) for GNSS airborne active antenna equipment designed to use the GPS or Gallileo L1 frequency

GLONASS is not covered by this MOPS. This MOPS only applies to the GPS and Galileo L1 frequency band.

2.2.1 GPS L1 Operating Frequency Range

The antenna unit shall operate over the minimum frequency range of 1575.42 MHz ± 10.23 MHz, unless otherwise specified for a particular parameter.

Figure 12: RTCA-DO-301

Figure 13: RTCA-DO-301 RF filter in graphical form

Table 2-2 Maximum Boresight Relative Frequency Response

Frequency (MHz)	Relative Response (dB)
1315 ≤ f < 1504.42	-50 dB
1504.42 ≤ f < 1554.42	Linearly increasing from -50 dB to -5 dB
1554.42 ≤ f < 1558.42	Linearly increasing from -5 dB to 0 dB
1558.42 ≤ f ≤ 1591.92	0 dB
1591.92 < f ≤ 1605.42	Linearly decreasing to -25.35 dB
1605.42 < f ≤ 1625.42	Linearly decreasing from -25.35 dB to -50 dB
1625.42 < f ≤ 2000	-50 dB

Figure 14: RTCA-DO-301 RF filter in numerical form

TYPICAL SOURCES OF GNSS INTERFERENCE

The following services are close to the GNSS frequencies and may use medium/high TX power or directional antennas affecting aircraft as well as ground installed (e.g. GBAS reference) GNSS antennas:

- UMTS (3G) telecom signals from ground and on board
- LTE (4G) telecom signals from ground and on board
- SATCOM (on board)
- RADAR
- Other point to point data links

See also presentation on IFIS 2016 in Belgrade. Reference below.

CONCLUSION

- Testing and trouble shooting of GNSS antennas need a special test set up and experience with reference data
- There is no simple standard answer to "selection of a perfect GNSS antenna".
- Each installation and service may require different selections
- The last years an increasing number of GPS problems show up. Some may be caused by defective or wrong selected antennas
- With the test set shown this can be measured, documented and evaluated even if antennas are installed

ACKNOWLEDGMENTS

Thanks to FCS, Flight Calibration Services in Braunschweig, Germany, to give permission to publish the results of the oscillating GPS antenna amplifier found on FCS Flight Inspection Aircraft.

REFERENCES

Critical impact given by the interference from LTE to the implementation of flight inspection in JAPAN, Kazuya Oguro, JCAB. Presented at IFIS 2016, Belgrade, Serbia.