Monitoring Pulse Based Navigation Signals in Flight

Rolf Seide
Senior Manager
Competence Center Flight Inspection Systems

Aerodata AG
Herrmann-Blenk-Strasse 36

D-38108 Braunschweig
Fax: +49 531 2359 222
E-mail: seide@aerodata.de

ABSTRACT

Most classical air navigation systems are using some kind of continuous modulation schemes. They are quite easy to monitor in detail with a "normal" flight inspection receiver and an oscilloscope.
Pulsed signals like DME/TACAN or all kinds of SSR transponder signals can not be monitored, decoded and checked for tolerance according to ICAO requirements in depth with standard Flight Inspection equipment. Even a modern digital storage oscilloscope can not perform this decoding in real time when interfaced to the FIS.
To monitor these signals, a state-of-the-art signal processing hardware, a dedicated "Pulse Decoder", had to be developed and integrated into the airborne FIS.
The unit was built, integrated and flight tested.
It is able to decode all SSR Transponder interrogations from the ground or TCAS aircraft in real-time and determine the type of interrogation (Mode 1, 2, 3/A, B, C, S with P4, S with P6 or user defined types).
Additional signal strength and counters for each pulse type are computed and presented in alphanumerical and graphical form. With this type of special data, plots like the "real antenna beam" including side lobes can be shown as received by the aircraft. Reflections on ground or any other interference can be detected and evaluated.

The same hardware, programmed in an other way, is able to monitor received pulses from a DME ground station in the FIS to monitor any unusual shapes, e.g. multipath effects on the pulses. The pictures are recorded in real-time synchronously with all other FIS parameters for additional detailed investigation after the flight, even in a "movie-like" stream. This is very helpful for discussion with the ground technicians.

An overview of the hardware installation and results from flights as taken in commissioning of ground stations are presented.

INTRODUCTION

Most classical air navigation systems are using some kind of continuous modulation schemes. They are quite easy to monitor in detail with a "normal" flight inspection receiver and (optional) an oscilloscope.
Pulsed signals like DME/TACAN or all kinds of SSR transponder signals can not be monitored, decoded and checked in depth with standard Flight Inspection equipment.

Even a modern digital storage oscilloscope can not perform this decoding in real time when interfaced to the FIS.
To monitor these signals, a state-of-the-art signal processing hardware, a dedicated "Pulse Decoder", had to be developed and integrated into the airborne FIS.

The unit was built, integrated in the FIS and flight tested.

The hardware is briefly introduced, and two examples are shown using the equipment.

1)SSR analysis

2)High speed DME-video sampling

HARDWARE
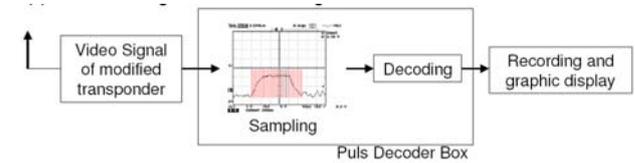
Figure: Signal flow

• Video Signals of a Transponder (Uplink, 1030 MHz) are sampled, decoded and analyzed in Real Time

• Individual Modes are counted (1,2,3/A,B,C,S4,S6), tagged with the corresponding signal level and time synchronized

• Output data are available on a high speed Ethernet connectable to any computer

• Programmable device, and therefore open for other applications, e.g. DME monitoring
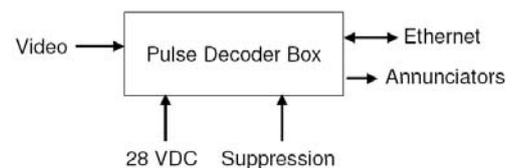
Figure: Blockdiagram, PCB and housing

SSR ANALYSIS

•The unit is programmed to decode Modes 1,2,3/A,B,C,S4,S6 and customized special pattern

•Each pulse is identified as per Mode, signal level and accurate time of occurrence

•The data are packed and transferred to the FIS computer for recording and graphical representation

•A few SSR examples are shown in the following

BASICS: STANDARD PULSES
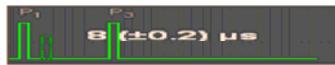
- Mode A
- Mode C
- Mode S (Frame)
- Mode S (Data)
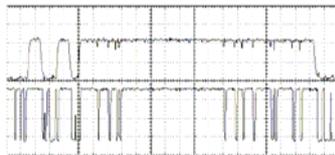
Figure:SSR Standard Pulses

BASICS: SIDE LOBE SUPPRESSION

Regulations in ICAO Annex 10, Volume IV, Chapter 3.1.1.5:
„Interrogation Side Lobe Suppression – Signals in Space"

3.1.1.5.1 The radiated amplitude of P2 at the antenna of the transponder shall be:

a) equal to or greater than the radiated amplitude of P1 from the side-lobe transmissions of the antenna radiating P1

and

b) at a level lower than 9 dB below the radiated amplitude of P1 within the desired arc of interrogation
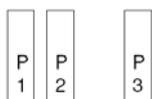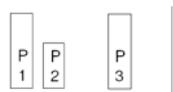
P2 according to a)   P2 according to b)

SSR GROUND STATIONS AND TCAS

- The following screen shots where taken from a new installed SSR station, located on a mountain 4000 ft high. The receiver was about 5 km / 3 nm away on an other montain.
- RX antenna was directional with +10 dBi gain

Station under test   RX antenna
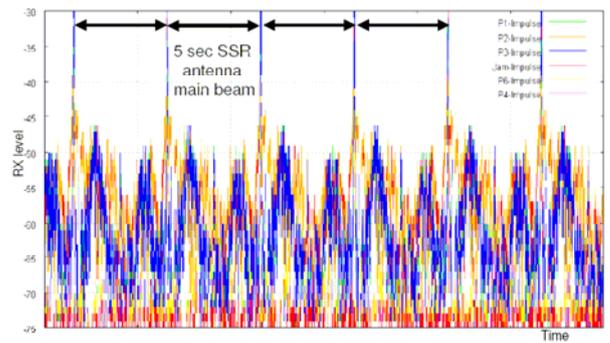
Figure: full sweep

- Detailed analysis of the full sweep showed, that an aircraft XPDR answers also in the side-beams, because the P2 level is not high enough compared to the P1/P3 level.
- By zooming into the recorded data, this can be found and printed. Step by step zooming is shown below.

Zooming in ...
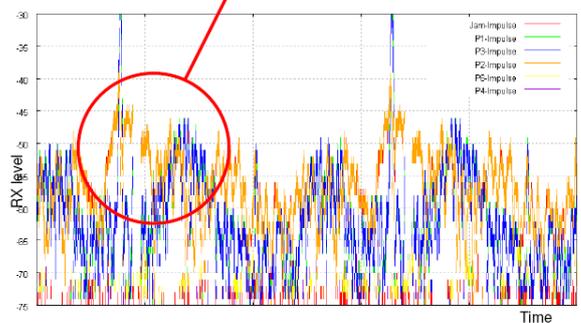
Zooming in ...
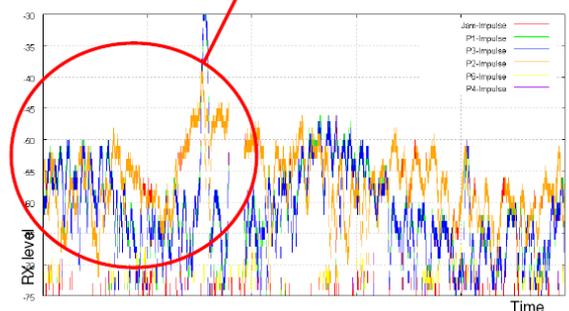
Zooming in ...
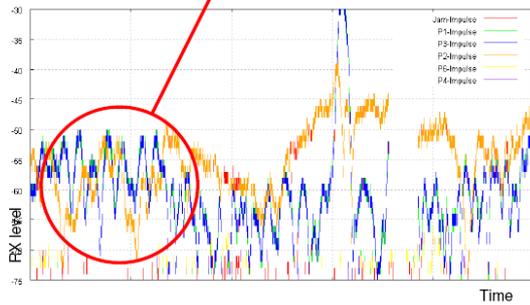
P2 pulses (orange) are more than 9 dB below P1/P3 (blue/green), resulting in valid answer of AC XPDR on a side-lobe
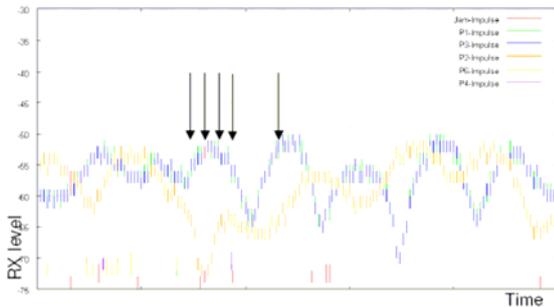
Figure: Final zoom with single pulses visible

ASYMETRIC P2 ANTENNA BEAM

An asymetric P2 antenna notch in the main direction was identified at one station. This is still within limits according to Annex 10, Vol.IV, but may be a hint to check the P2 antenna.
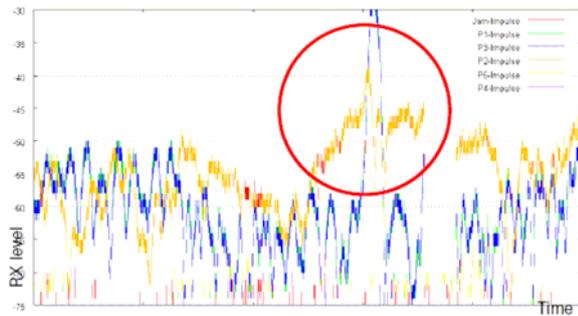
Figure: asymmetric P2 antenna beam (orange)

2 GROUND STATIONS

2 different ground stations can be identified, one clearly shown as a Mode S station with about 10 dB more than a Mode A/C station. The airborne XPDR was set to Mode A/C replies only.
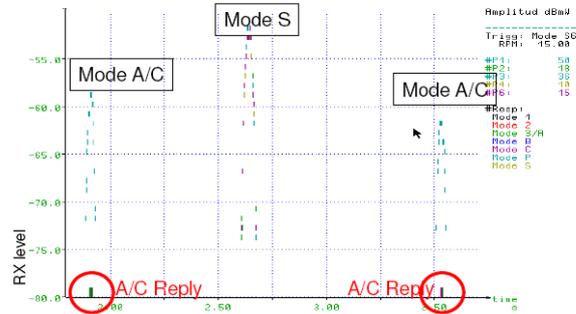
Figure: Two independent SSR ground stations identified

The shape of main antenna beam can be shown in detail together with the airborne XPDR replies.

Figure: Detail of main beam with XPDR replies

SSR GROUND STATIONS AND TCAS

Some other signals show up together with the SSR ground station, not related to the antenna speed of 5 sec per turn.
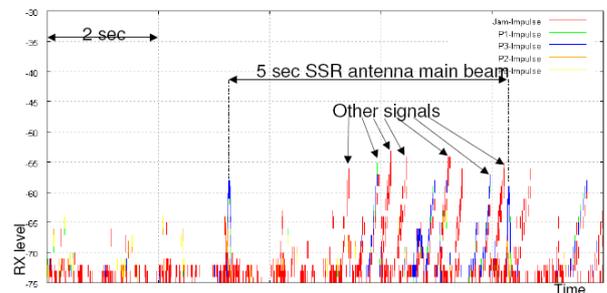
Figure: Non ground based interrogations

• The other signals received where identified as TCAS interrogations of aircraft flying near by.
• The interrogation level is –55 dBm and –65 dBm

• The sequence identified was a „whisper-shout-sequence", used from airborne TCAS to identify aircraft

around the own position. It starts with a low power signal to interrogate aircraft near by increasing to higher levels for aircraft far away.
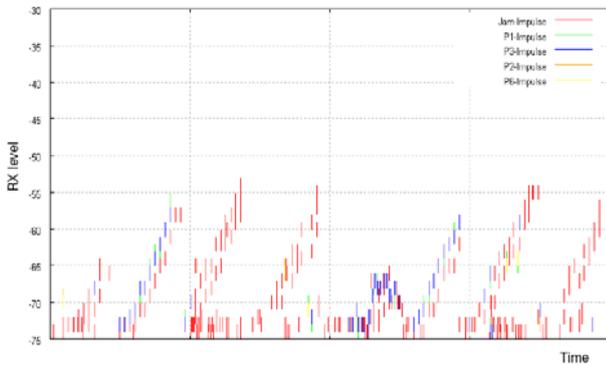
Figure: Whisper-shout TCAS interrogation

Only by knowledge of possible waveforms different interrogations could be separated

UNIDENTIFIED INTERROGATION

This plot was recorded while regularly monitoring a ground station. A second station showed up.
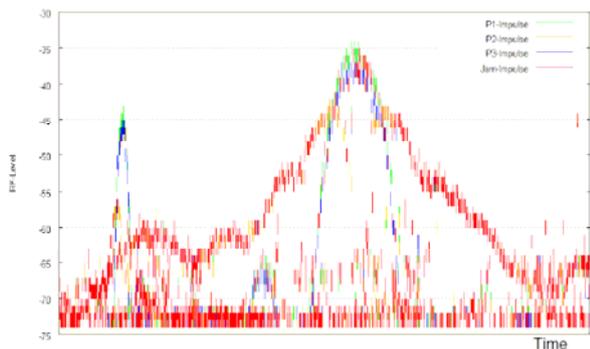
Figure: New station coming up, all pulses shown
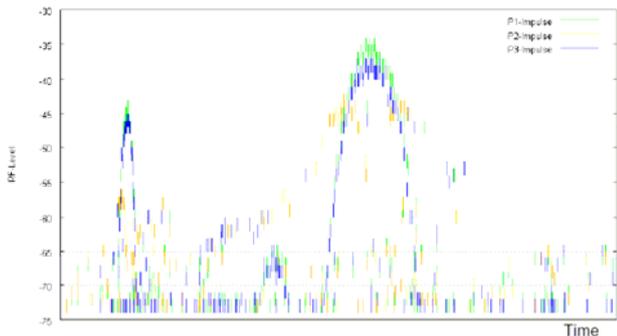
Figure: New station coming up, pulses filtered

EXAMPLE DME GND STATION

•The unit was set-up to operate as a high-speed storage oscilloscope to monitor DME video. •It was focused on DME multipath.
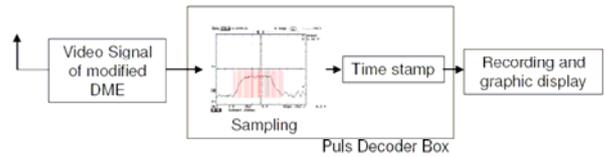
Figure: Block Diagram in DME Mode

INTERNATIONAL REGULATIONS, DME

•
ICAO DOC 8071, Vol. 1, Chapter 3.3.10 shows:

Pulse shape

3.3.10   It is not easy to measure the pulse shape of the DME transponder signal in orbital or radial flight due to multipath effects. The amplitude of the RF signal will vary along the flight path. The preferred method is to store a waveform of the pulse pair on a digital oscilloscope and use the timing functions of the instrument to average the calculated parameters over a series of samples.

DME MULTIPATH

DME multipath comes up unexpected and effects the performance of the airborne DME unit.
It can have effects in
• reduced reply efficiency
• Unstable signal strength
• DME „memory mode"
• Unlocks
  or, in worst cases
• wrong distances

DME MULTIPATH RECORDING

In Standard FIS:
•For multipath troubleshooting an oscilloscope is used and the screen is monitored manually. Documentation is no more than a single screen shot as print out.

•In replay of the data after the flight on ground a detailed investigation is not possible.

Challenge of new hardware:

• The video signal is recorded in high speed and shown together with all relevant FIS data as well as aircraft positioning information in a fully integrated replay mode.

•Single step replays and overlays of the actual position on a map is used to locate potential reflectors

EXAMPLE: DME MULTIPATH

The following examples were taken from a DME station showing heavy multipath on dedicated spots (X-channel)
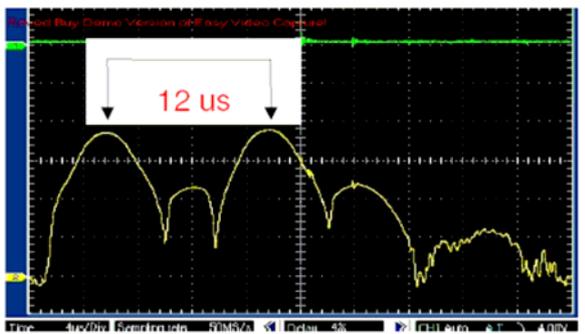
Figure: One Series of Echos
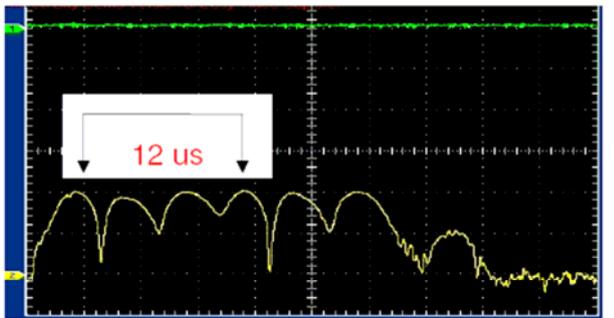
Figure: Several Series of Echos

While flying, a "movie-type" film is recorded. It can be replayed together and synchronized with the standard FIS DME data like distance error, reply rate, squitter rate, AGC and memory flag.

In flight or later on ground, every single picture can be assigned to the location, speed, altitude, attitude and heading information.

In normal speed replay mode, the film is shown identical as in flight. After a corrective action of modifying reflections on ground, the same track can be re-flown and compared to previous results. This gives a very good proof of the effect of the measures taken.

CONCLUSIONS

•Pulsed signals are not easy to monitor in a classic Flight Inspection System

•If malfunction is detected, for trouble-shooting purpose or detailed data for commissioning is required, real-time data must be recorded and made available for later analysis.

•To detect relationship between bad results of a navigation system and pulse related effects, the data recorder must be fully integrated into the FIS software and hardware

•A dedicated, customized decoder is the only solution for effective work in this matter

ACKNOWLEDGMENTS