A Blind Adaptive Equalizer for SOQPSK :
A Unique System to Combat both Multipath and Antenna Daisy Pattern

G.Blanc, A.Skrzypczak and J.-G.Pierozak

ZODIAC DATA SYSTEMS

ITEA – 20th Test Instrumentation Workshop

May, 11th 2016

Speaker: Jean-Guy Pierozak

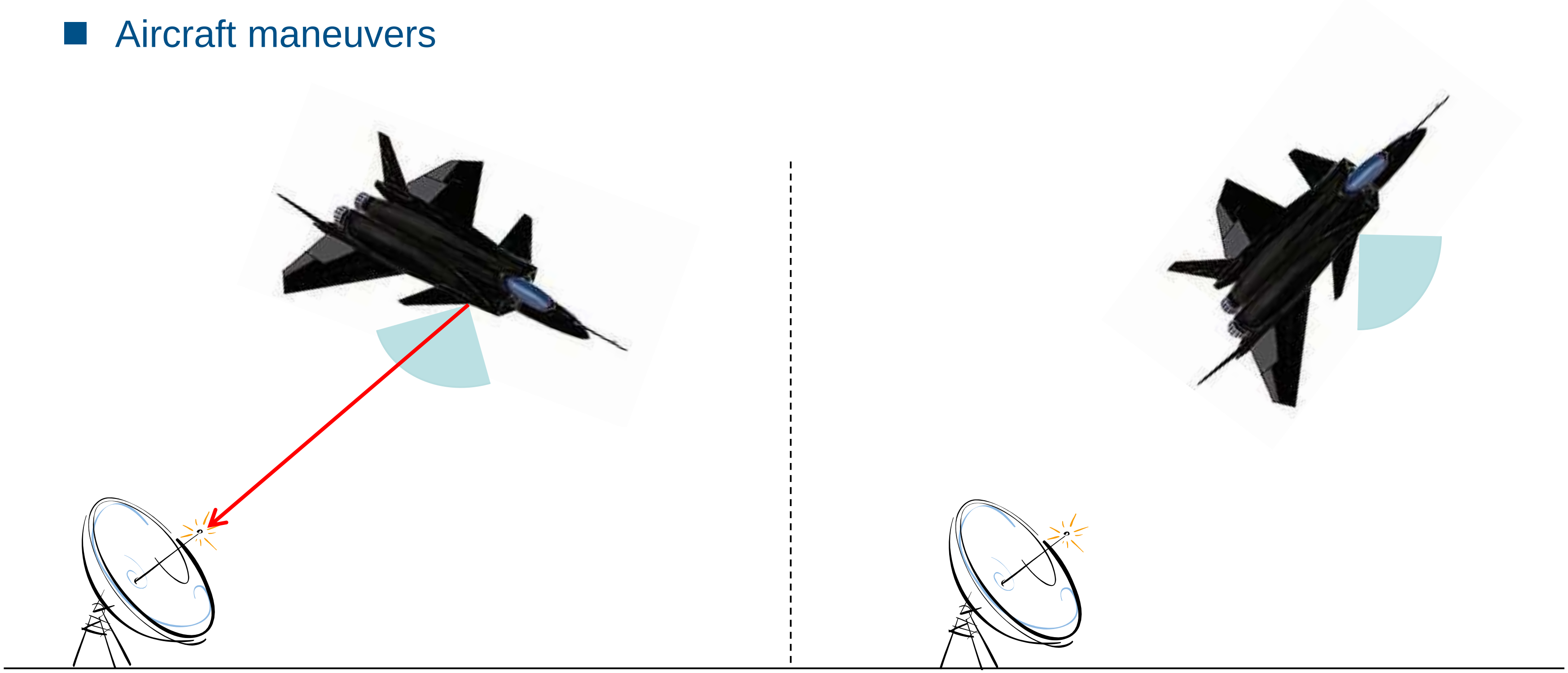
Introduction

- **Distortions affecting the datalink availability during a flight test mission:**
  - Thermal noise ➔ mitigated using Channel Coding (ex: RS, LDPC)
  - Multipaths ➔ mitigated using Equalization
  - Antenna Daisy Pattern (“2-Antennas Problem”) caused by Co-Channel Interference when using two antennas
- **IRIG106-15 ➔ Space-Time Coding (STC) to mitigate the “2-Antennas Problem”**
- **Zodiac Data Systems (ZDS) proposes an alternate solution based on delay diversity and an adaptive equalizer**
- **ZDS presented this solution for PCM-FM at ITC’15**
- **Goal of this presentation = prove the feasibility in SOQPSK**

- Introduction
- **Description of the “2-Antennas Problem”**
- Available solutions
- ZDS proposed solution
- Laboratory experiment setup
- Laboratory experiment results
- Conclusion

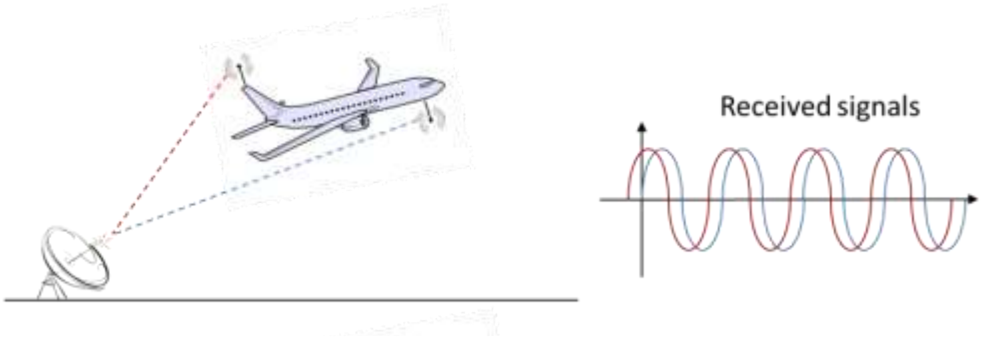
2-Antennas Problem Description

- **A unique antenna on an aircraft is generally not sufficient to ensure a full availability of the datalink**
  - Directive antennas / Masking
  - Aircraft maneuvers



2-Antennas Problem Description

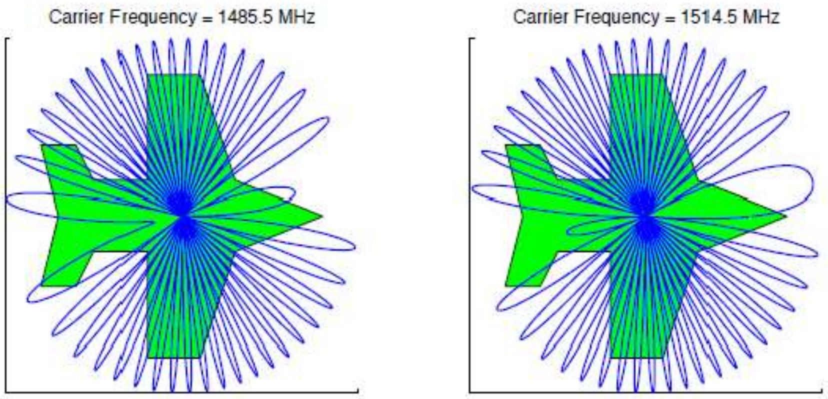
- **Introduction of a second antenna on the aircraft**
  - Signal emission is done with the same central frequency to optimize spectral occupancy
  - Shift in phase between both signal may occur
  - In such a case, received signals may have an opposite phase ➔ recombination leads to complete signal loss



2-Antennas Problem Description

- **The signal is lost for different pointing directions between the aircraft and the receiving antenna**
  - Depends on the signal frequency,
  - Depends on the aircraft position w.r.t the receiving antenna,

- **Radiation diagram with daisy patterns / porcupine effect**



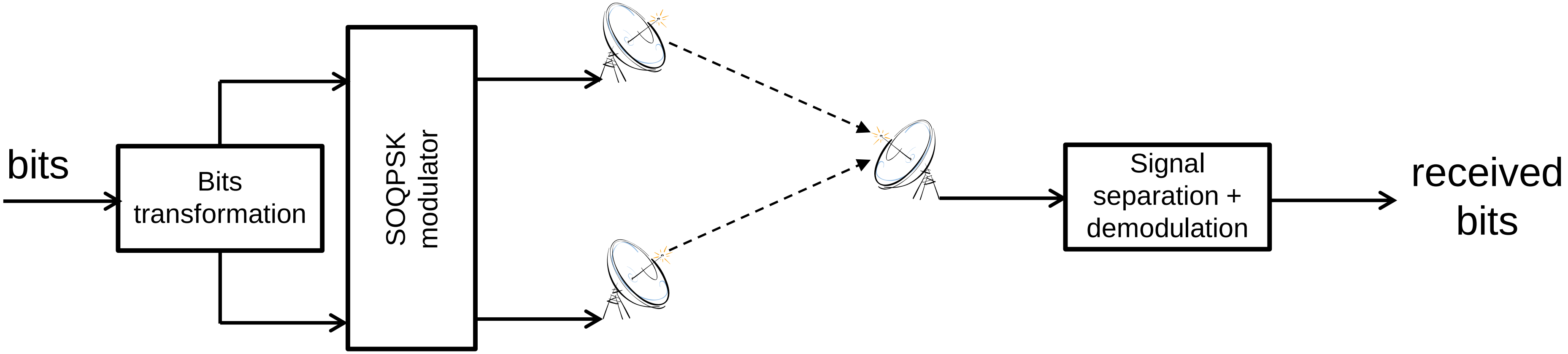
From M. Rice and K. Temple, “Space-Time Coding for Aeronautical Telemetry: Part II – Experimental Results”, in ITC 2011.

- Introduction
- Description of the “2-Antennas Problem”
- **Available solutions**
- ZDS proposed solution
- Laboratory experiment setup
- Laboratory experiment results
- Conclusion

Solving the 2-Antennas Problem

- **First solution: reducing the transmitting power of one antenna**
  - Around 6 to 10 dB of signal attenuation
  - Avoids signal cancellation
  - But impact on the budget link if the transmission is made with the attenuated signal

- **Second solution: Space-Time Coding**
  - Proposed by M. Rice in ITC’2011 for SOQPSK
  - Included in IRIG106-15
  - Principle:



Solving the 2-Antennas Problem

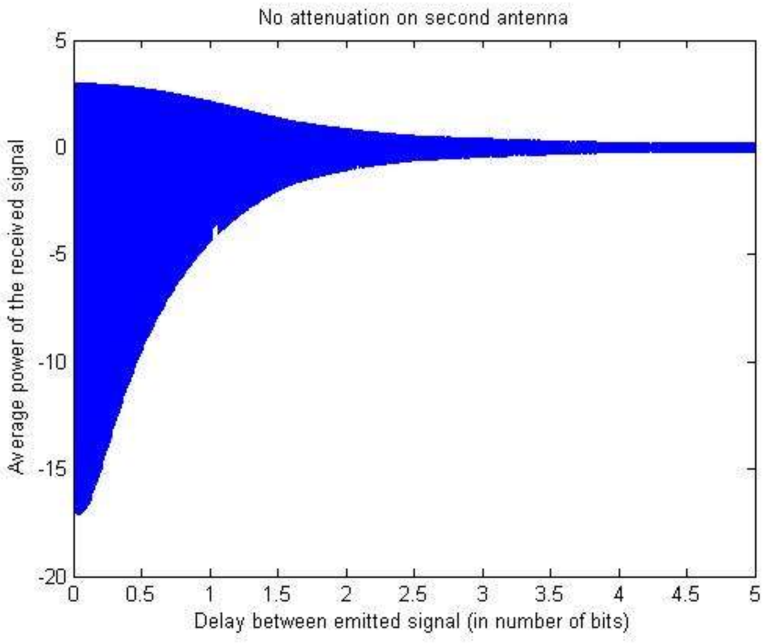
- **STC-based solution**
  - Pros:
    - ❑ Efficient solution to solve the 2-Antennas Problem
    - ❑ Proven by on-site experiments ([1])
  - Cons:
    - ❑ Specific modulator required & two transmitters
    - ❑ Specific demodulator required
    - ❑ Pilot insertion: 4% loss of useful data & latency for acquisition
    - ❑ Sensitive to multipath channels ([1])
    - ❑ Equalization with STC is complicated

[1] : ITC'14 – Performance Evaluation of Space-Time Coding on an Airborne Test Platform – Kip Temple

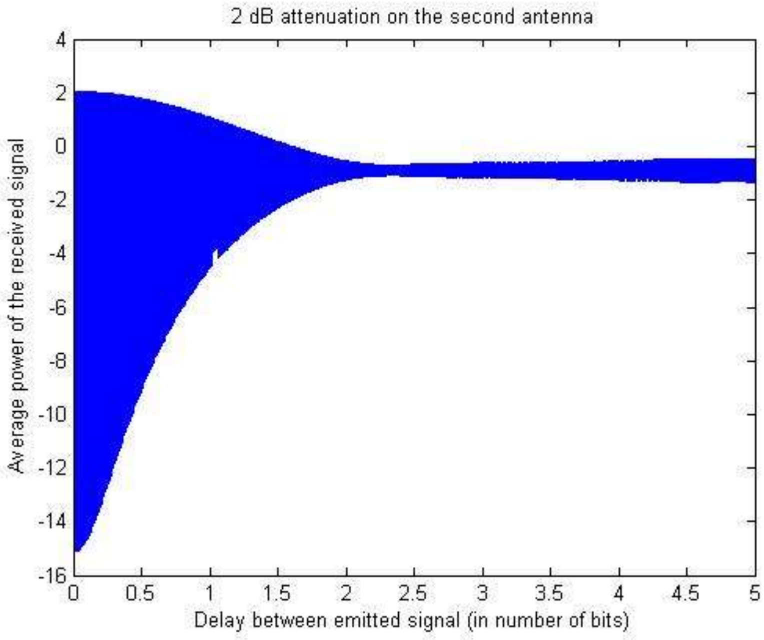
- Introduction
- Description of the “2-Antennas Problem”
- Available solutions
- **ZDS proposed solution**
- Laboratory experiment setup
- Laboratory experiment results
- Conclusion

ZDS Solution

- **We use delay diversity: introduction of a short delay between antennas**
  - Antenna 1: $s(t)$
  - Antenna 2: $s(t-\tau)$
  - Attenuation on antenna 2: α



No attenuation on second antenna



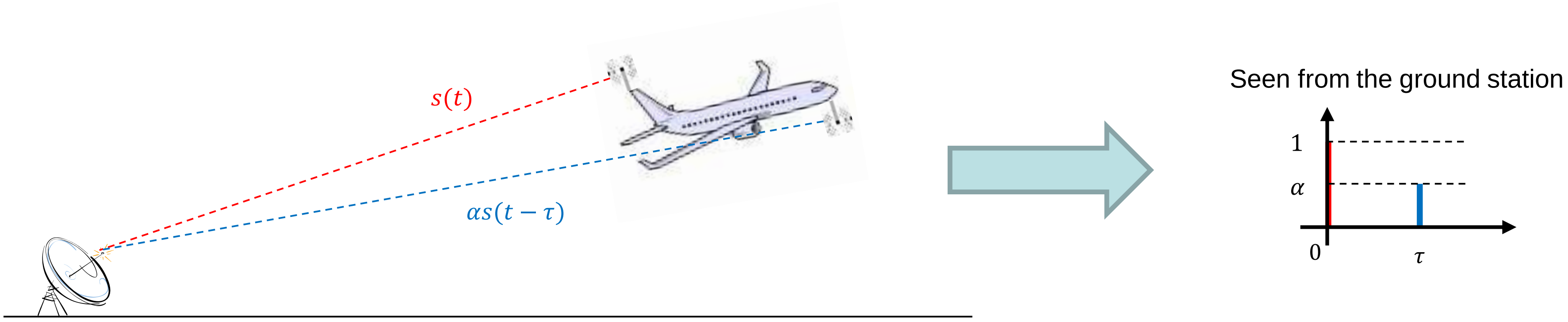
2 dB attenuation on the second antenna

- **The 2-antennas problem is solved if τ > 2.5 bits**

ZDS Solution

- **Received signal:** $r(t) = s(t) + \alpha s(t-\tau) = s(t) \otimes \underbrace{(\delta(t) + \alpha\delta(t-\tau))}_{h(t)}$

- **Received signal is seen as if it passes through a 2-path channel**



- **Looks like a multipath problem ➔ can be mitigated using an equalizer**

ZDS Solution

- Concept was **field proven** by ZDS during development of **COFDM solution** for **Airbus**

  ITC’13 – Paradigms Optimization for a C-Band COFDM Telemetry with High Bit Efficiency (ZDS)

- Concept was **proven in laboratory** by ZDS in **PCM-FM** using an adaptive blind equalizer

  ITC’15 – Limitation of the 2-Antennas Problem for Aircraft Telemetry by using a Blind Equalizer (ZDS)

- Now, ZDS introduces an **adaptive blind equalizer** for **SOQPSK**

  ➔ Prove that the concept also works for SOQPSK

- Introduction
- Description of the “2-Antennas Problem”
- Available solutions
- ZDS proposed solution
- **Laboratory experiment setup**
- Laboratory experiment results
- Conclusion

Testbench

SMBV 100 A

- **SMBV 100 A: signal generator**
  - PN15 pseudo-random bit sequence
  - SOQPSK modulation
- **AMU 200: channel propagation simulator**
- **Zodiac Radio Telemetry Receiver (RTR) with SOQPSK equalizer**
  - Signal demodulation
  - BER evaluation

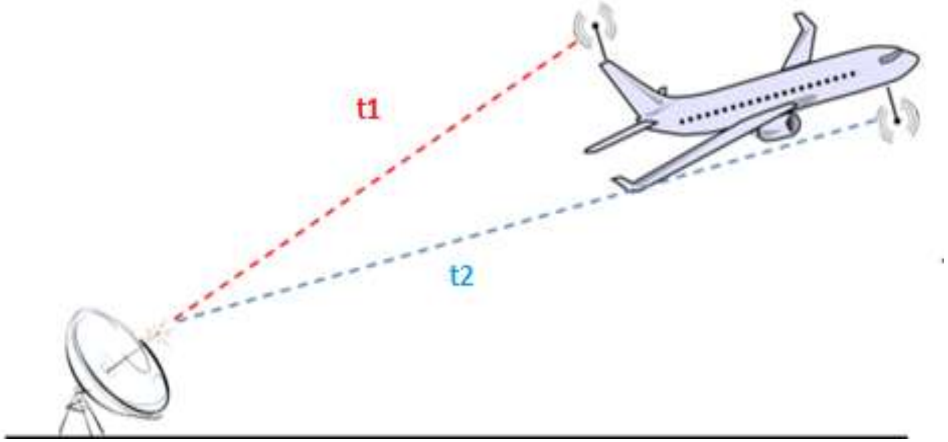
Method

- **Bit rates considered: 1Mbps to 5Mbps (comparison with PCM-FM)**

- **For each bit rate find a set of parameters (α, τ) meeting the following requirements:**
  - Datalink availability: power attenuation corresponding to α as low as possible
  - Equalizer constraint: power attenuation corresponding to α as important as possible
  - 2-Antenna Problem solving: τ greater than 2.5 bits
  - Equalizer constraint: τ remaining in the correction span of the equalizer

- **Test principle:**
  - Choose α then find a value of τ so that the BER remains equal to zero
  - If no value of τ is found decrease α and start again

Influence of time-varying channel



- $\tau_d = |t_2 - t_1|$ is time-varying depending on the maneuvers of the aircraft
- $\tau_d^{max} = \frac{d}{c}$ with d distance between antennas and c speed of light.
- $d = 75m$ (Airbus A380) ➔ $\tau_d^{max} = 0.25$µs

Influence of time-varying channel

- **Delay seen by the receiver is not exactly τ, but a delay varying dynamically in the range $\left[\,\tau_{low}\,;\,\tau_{high}\,\right] = [\,\tau - 0.25\mu s\,;\tau + 0.25\mu s\,]$**

- **The AMU 200 does not allow dynamic variations of the delay τ ➔ we propose to actually determine two sets (α, τ_{low}) and $\left(\alpha, \tau_{high}\right)$ meeting the requirements previously mentioned**

AMU Settings

Path	Profile	Path Loss (dB)	Delay (µs)	Const. Phase (Deg)
1	Static path	0	0	0
2	Const. Phase	2	variable	variable

Attenuation of antenna 2 α is set to 2 dB

τ

Phase difference between the two signals

The BER must remain equal to 0 for all values of the phase difference between the two paths

- Introduction
- Description of the “2-Antennas Problem”
- Available solutions
- ZDS proposed solution
- Laboratory experiment setup
- **Laboratory experiment results**
- Conclusion

Test Results

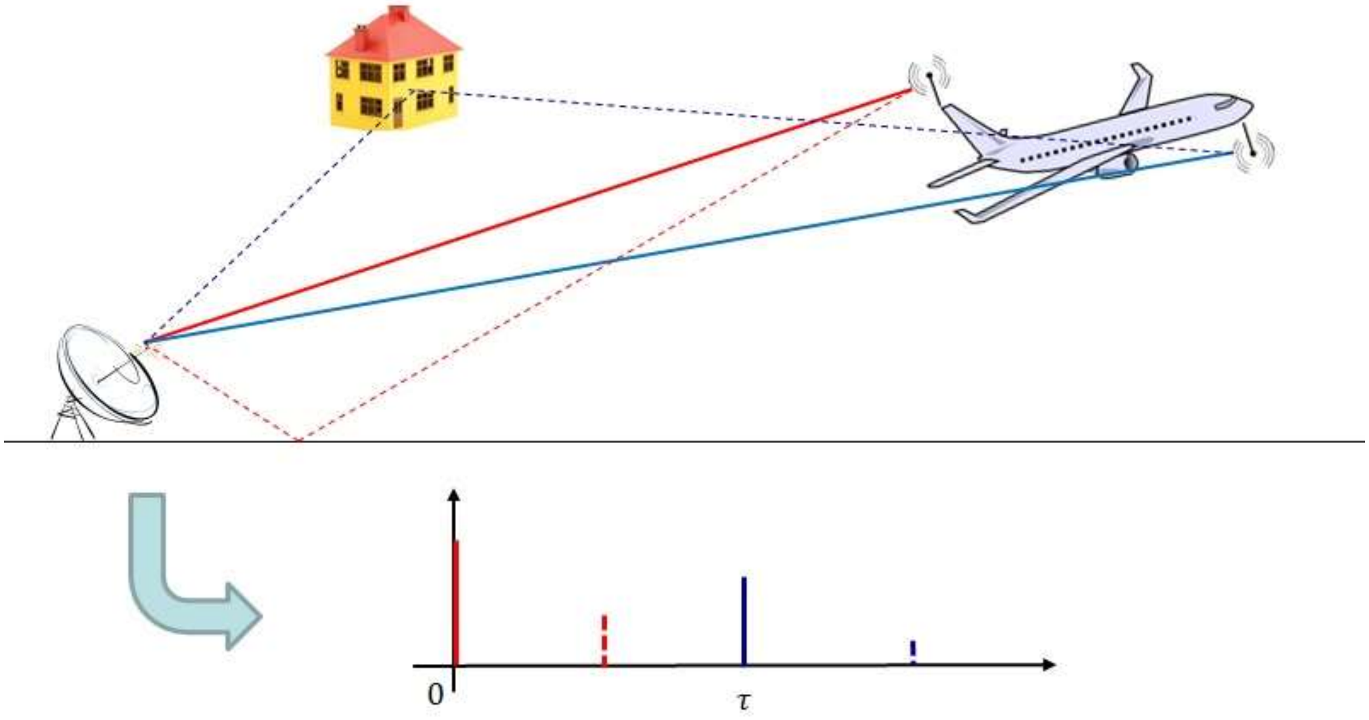
Data Rate	**1Mbps**	**2Mbps**	**3Mbps**	**4Mbps**	**5Mbps**
α (dB)	2	2	2	2	2.5
τ_{low}	3.5 µs 3.5 bits	1.7 µs 3.4 bits	1.2 µs 3.6 bits	0.8 µs 3.2 bits	0.7 µs 3.5 bits
τ_{high}	4 µs 4 bits	2.2 µs 4.4 bits	1.7 µs 5.1 bits	1.3 µs 5.2 bits	1.2 µs 6 bits

- **Conclusions:**
  - α corresponds to a power attenuation lower or equal to 2.5 dB
  - τ_{low} and τ_{high} are greater than 2.5 bits ➔ the two-antenna problem is solved
  - τ_{low} and τ_{high} match the requirement of distance of 75 meters between antennas (worst case scenario)

➔ The experiment is successful

Influence of Multipaths Channels

- **Robustness of this solution w.r.t multipaths channels ?**
  - Simulation: one reflected path for each antenna
  - Rayleigh fading model with 30Hz Doppler

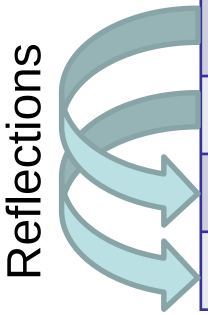


Influence of Multipaths Channels

- **Configuration of AMU 200**

Value obtained from previous tests

Path	Profile	Path Loss (dB)	Delay (µs)	Const. Phase (Deg)	Res. Doppler Shift / Hz
1	Static path	0	0	0	0
2	Const. Phase	2	τ	0	0
3	Rayleigh	20	0,7	0	30
4	Rayleigh	20	τ + 0.5 µs	0	30



Influence of Multipaths Channels

- **Test results**

Data Rate	Attenuation (dB)	Delay τ (µs)	BER
1	2	4	1.6e-4
2	2	2	3.2e-5
3	2	1.5	1.2e-5
4	2	1	1.3e-5
5	2.5	1	1.5e-5

- **Conclusions**
  - BER is acceptable level in presence of multipath
  - LDPC (IRIG106-15) will help the transmission to become Quasi-Error Free
  - Simultaneous mitigation of Multipaths and 2-antennas problem is possible

Conclusions

- **ZDS solution:**
  - Pros:
    - Pragmatic and cost-effective solution to solve the 2-Antennas problem in SOQPSK
    - Slight modification of the on-board setup: delay line (FPGA-based)
    - No need to modify the receiver (equalizer is a software option)
    - Enables simultaneous correction of Multipaths and 2-Antennas Problem
  - Cons:
    - Requires attenuation of one of the antennas (2 to 2.5 dB)

- **Good compromise between cost and performances**

- **Next:**
  - Test the solution in a real environment
  - Quantify the performances of the adaptive blind SOQPSK in combination with LDPC

Questions ?