

Analysis of an IQ Receiver Model by means of Laboratory Measurements for Conventional VOR

Seif Ben-Hassine, Alexandre Chabory, Christophe Morlaas, Rémi Douvenot

ENAC, TELECOM-EMA, Université de Toulouse, Toulouse, France

Funded by



December 6, 2019
EMWT 2019, Toulouse, France

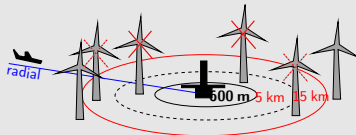


VOR system

- VOR gives an aircraft its bearing (azimuth) with respect to a ground beacon
- VHF frequency band (108-118 MHz), horizontal polarization
- Two components : a reference signal (REF) and a variable azimuth-dependent signal (VAR)
- Two types of VOR station : Conventional VOR and Doppler VOR

Building restricted areas

- Multipath yields bearing errors in the VOR system
- Surrounding objects can be a potential major contributor to this error and particularly wind turbines
- ICAO recommendations exist but the applied rules differs between countries



Introduction

ENAC-EMA contribution

- Static VOR error accuracy has been given in [*Morlaas et al.*, ITAES 2008]
- In [*Morlaas et al.*, Eucap 2010], a hybridization of parabolic equation with physical optics has been proposed, called VERSO for VOR Error SimulatOR
- Improvements of this method have been discussed in [*Claudepierre et al.*, Eucap 2015]
- Confrontation with in-flight measurements at Boulogne-sur-Mer in [*Claudepierre et al.*, Eucap 2016]
- In [*Ben-Hassine et al.*, EuCAP 2019], a digital IQ receiver model including filtering and demodulation responses, has been developed ⇒ Take into account the variations in time of multipath in the bearing error

Previous study : measurements of VOR signals

- Measurements have been performed in [*Bredemeyer, FCS 2015*] to analyze the effect of multipath on Doppler VOR signal

Objectives

- Develop a tools to assess the impact of wind turbines on bearing in dynamic context
- Analyze the response of digital IQ receiver model for a conventional VOR signal by means of
 - VHF measurement for one canonical multipath
 - Baseband IQ measurement in complex realistic scenarios
⇒ Compare the digital IQ receiver model with a calibration receiver

Plan

- 1 Introduction
- 2 VOR Receiver Model
- 3 Confrontation from VHF measurements
- 4 Confrontation from baseband IQ measurements
- 5 Conclusion

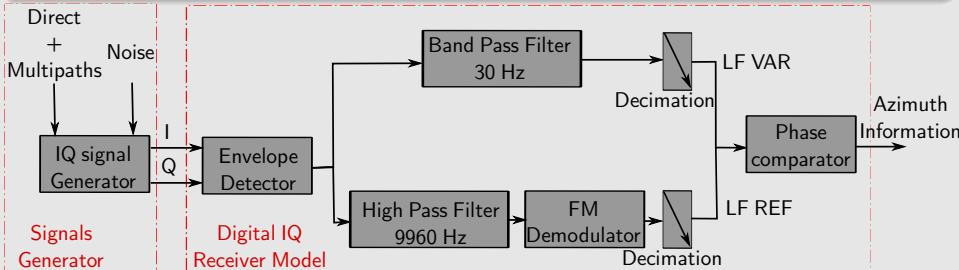
VOR Receiver Model

Objective

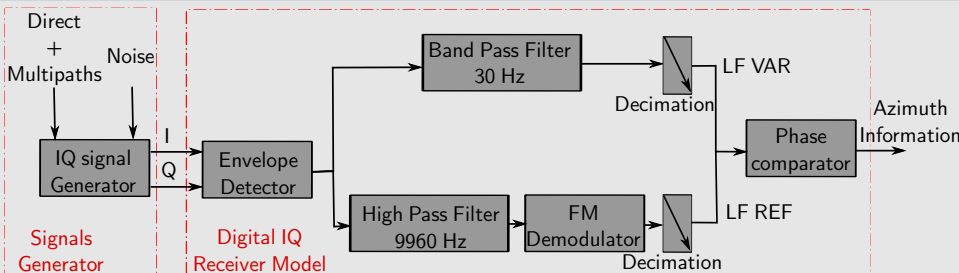
- Present the digital VOR receiver model

Proposed model

- Developed model based on I/Q signals
- **Signal generator**
 - Generate I/Q channels from time series of multipath parameters
- **Digital IQ receiver model**
 - Envelope detector
 - VAR channel
 - REF channel
 - Azimuth estimation



VOR Receiver Model



Used model parameters

- IQ sampling frequency = 25 kHz
- Decimation rate = 210
- Filtering parameters

	Type	F_{pass} (Hz)	F_{stop} (Hz)	R_{pass} (dB)	R_{stop} (dB)
Band pass filter 30 Hz	Butterworth	[29,31]	[24,36]	0.1	30
Low pass filter DC	Butterworth	1	2	0.1	20
High pass filter 9960 Hz	Kaiser	8000	7000	∅	60

Plan

- 1 Introduction
- 2 VOR Receiver Model
- 3 Confrontation from VHF measurements
- 4 Confrontation from baseband IQ measurements
- 5 Conclusion

Problematic with in-flight measurements (1)

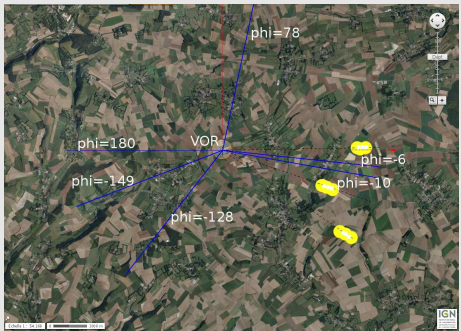


Figure 3 – Wind farm located at 5 km from the VORC station in Boulogne-sur-Mer

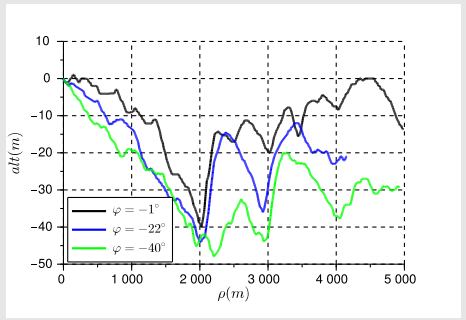


Figure 4 – Relief from the VOR station to the wind turbines

Parameters

- Antenna of the Boulogne-sur-Mer VORC (113.8 MHz)
- 9 windturbines on 3 radials
 - Mast : ground diameter = 7.5 m, top diameter = 2 m, height = 98 m
 - Nacelle : 4 m × 11 m × 4 m
 - Blades : length = 35.5 m
- Ground with relief

Problematic with in-flight measurements (2)

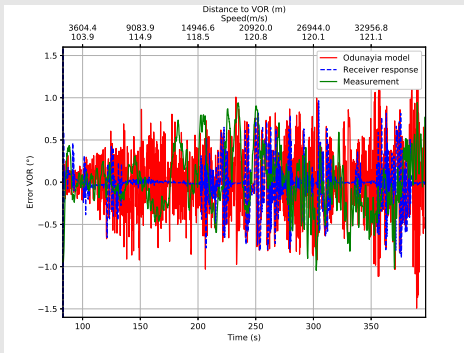


Figure 5 – Measured and simulated bearing error on radial $\varphi = 78^\circ$

Analysis

- Good agreement for the error maximal value
- Differences between simulations-measurements
 - Residual error without wind turbines (other scatterers, noise)
 - Atmospheric effects
 - Time variation of multipath
 - Deficiencies in the configuration characteristics

⇒ Measurement parameters must be controlled to improve the analysis of our receiver behaviour

Confrontation from VHF measurement : Description (1)

Objective

- Compare the digital IQ receiver model with a calibration receiver by processing a VHF signal for one canonical multipath in controlled environment

Measurement campaign

- Generation of baseband VOR signals (direct + multipath)
- VHF AM modulation
- Combination/Splitting of VHF signals
- Analog to IQ digital converter
- Receiver processing
 - R&S EVS300
 - Digital IQ receiver

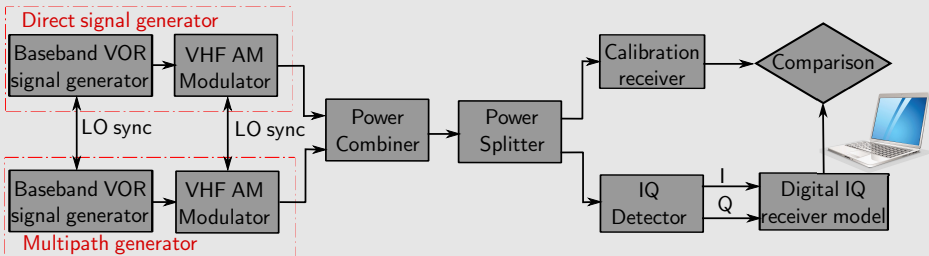
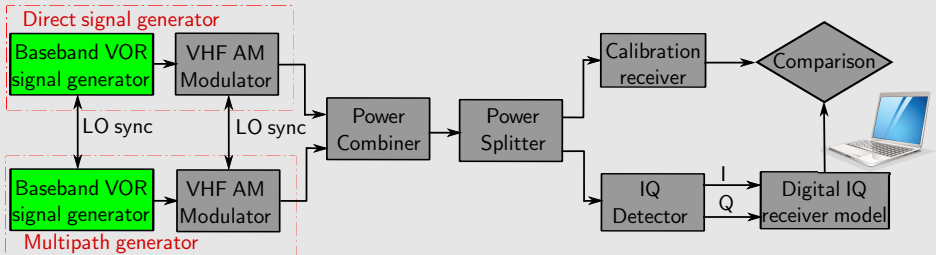


Figure 6 – Block diagram of measurement campaign

Confrontation from VHF measurement : Description (2)

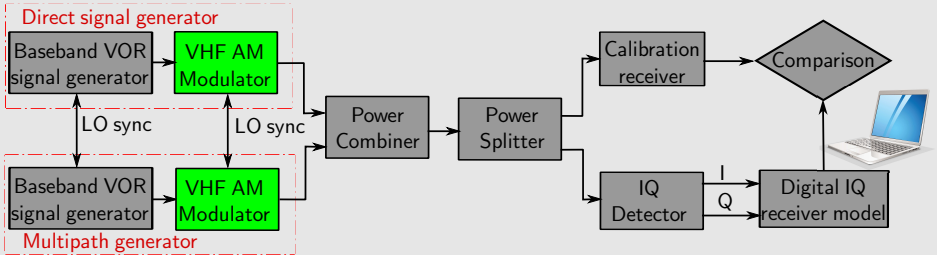


Generation of baseband VOR signals

- HP 8904A generator
- Generate the baseband VOR signals (direct + multipath)
- Synchronized LF phases



Confrontation from VHF measurement : Description (3)

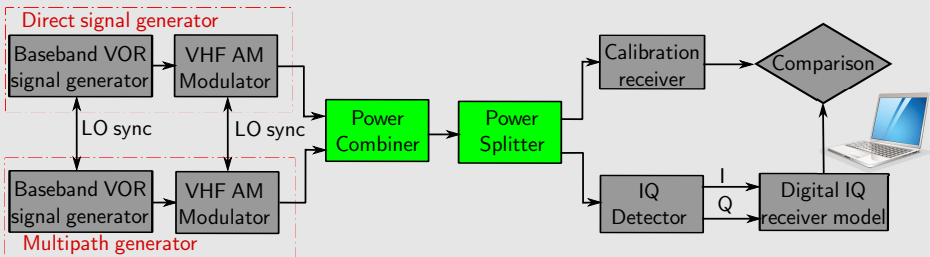


VHF AM modulation

- Rohde & Schwarz SMA100
- Generate an amplitude-modulated VHF signals
- Synchronized RF phases



Confrontation from VHF measurement : Description (4)

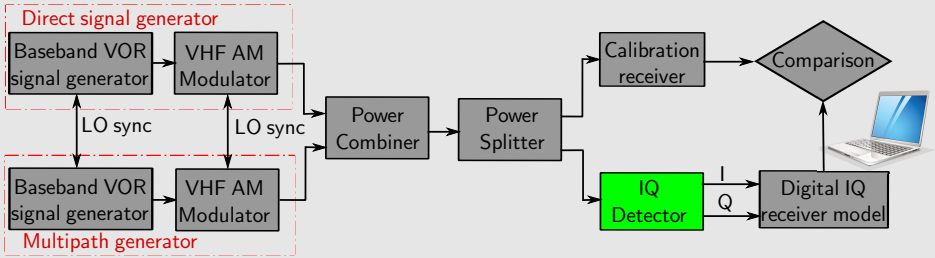


Combination/Splitting of VHF signals

- Power splitter/combiner ZFSC-2-5
- Combine the direct signal and the multipath
- Divide the signals towards the two type of receivers



Confrontation from VHF measurement : Description (5)

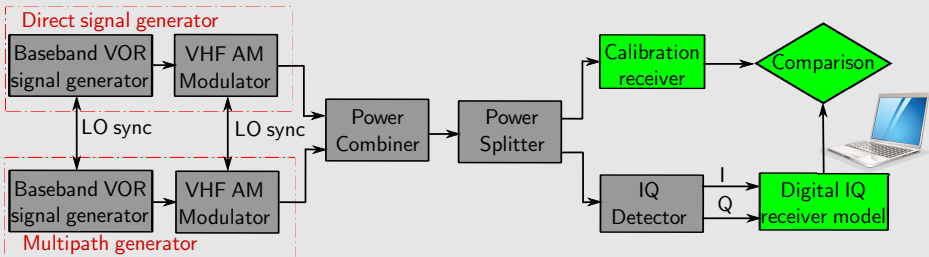


Analog to IQ digital converter

- TNT-SDR dongle type Nooelec R820T2
- Recover the baseband VOR signal
- Analog to IQ digital converter
- Save IQ binary data



Confrontation from VHF measurement : Description (6)

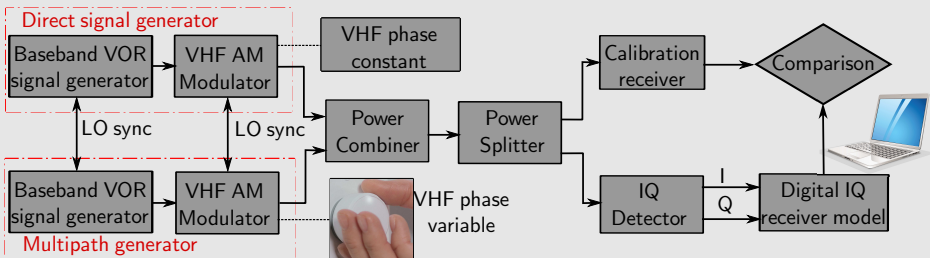


Calibration receiver

- Rohde & Schwarz EVS300
- ILS/VOR analyzer
- Measure the azimuth information via RF input
⇒ to compare with digital IQ receiver model



Confrontation from VHF measurement : Description (7)



Measurement process

- The parameters of the IQ receiver model are fixed
 - Band pass filter 30 Hz
 - High pass filter 9960 Hz
 - Low pass DC filter
- Set an azimuth difference between direct and multipath at a value of 90°
 - ⇒ maximize the conventional VOR error
- Manual variation of the RF phase shift between the direct signal and the multipath
 - ⇒ generate variations on the bearing error

Confrontation from VHF measurement : Results

Confrontation result

- CVOR frequency = 113 MHz
- Recording time = 6 mn
- VHF direct signal
 - Power = -50 dBm
 - Azimuth = 0°
 - Phase = 0°
- VHF multipath signal
 - Power = -70 dBm
 - Azimuth = 270°
 - Variable phase in [-90°, 90°] by hand random turning

Analysis

- Relative similarity between the behaviours of digital and calibration receiver
- Delay between the two responses

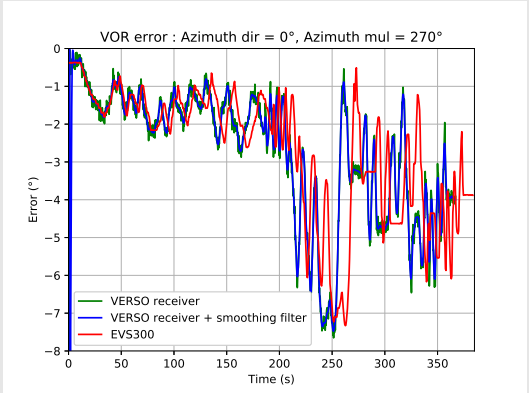


Figure 7 – Receivers responses

Plan

- 1 Introduction
- 2 VOR Receiver Model
- 3 Confrontation from VHF measurements
- 4 Confrontation from baseband IQ measurements
- 5 Conclusion

Confrontation from baseband IQ measurement : Description

Objective

- Compare the digital IQ receiver model with a calibration receiver by processing a baseband IQ signal in complex scenario

Measurement campaign

- Generation of baseband IQ signal in a complex scenarios computed with a multipath times series simulator
- Transmission of IQ data by means of standard sound card to R&S EVS300 receiver via its LF input
- Receiver processing by ; static model (Odunaiya), digital IQ receiver model and R&S EVS300

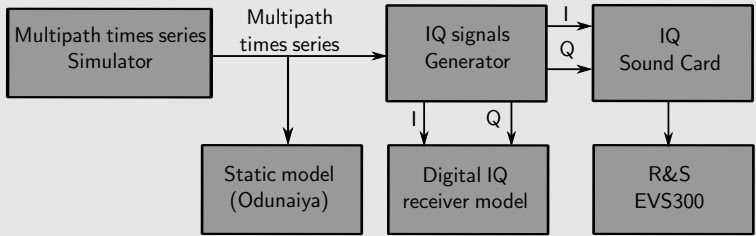
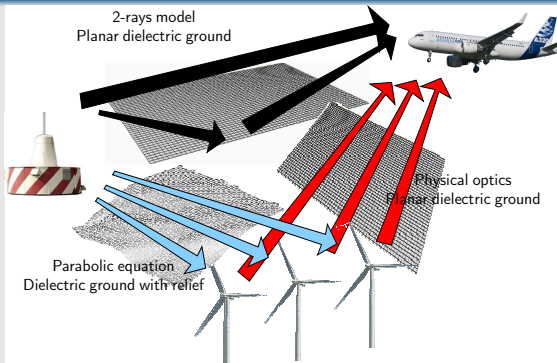


Figure 8 – Block diagram of measurement campaign

Multipath times series simulator



Input/output

Input

- VOR station position and radiation pattern
- Positions and characteristics of the wind turbines
- Relief
- Aircraft trajectory
- Space sampling step of trajectory
- Aircraft speed

Output

- Time series of multipath parameters : amplitude a_n , phase θ_n and azimuth φ_n (relative to Magnetic North)

Confrontation from baseband IQ measurement : Configuration

Configuration

- CVOR station
 - $F = 113.8 \text{ MHz}$
 - $P = 50 \text{ W}$
- 1 wind turbine is placed at 1 km from the VOR
 - Simplified model
 - Based on ENERCON E82 size
 - Mast : ground diameter = 7 m, top diameter = 3 m, height = 90 m
 - Nacelle : $3 \text{ m} \times 3 \text{ m} \times 3 \text{ m}$
 - Blades : length = 10 m
- VOR Receiver
 - Straight trajectory of 15 km
 - Departure = $[500, 0, 1000] \text{ m}$
 - Speed = 180 km/h
 - Space step = $\frac{\lambda}{5} \simeq 0.526 \text{ m}$
 - Motionless for the first 5 s

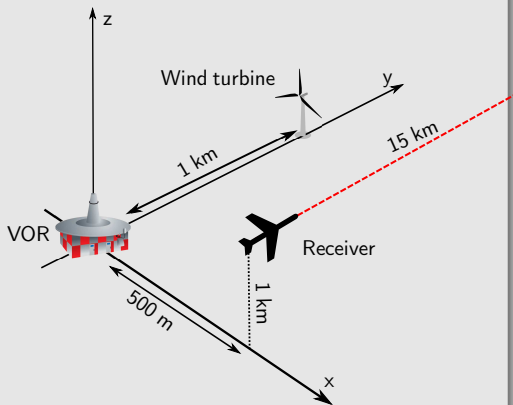


Figure 9 – Configuration

Confrontation from baseband IQ measurement : Results (1)

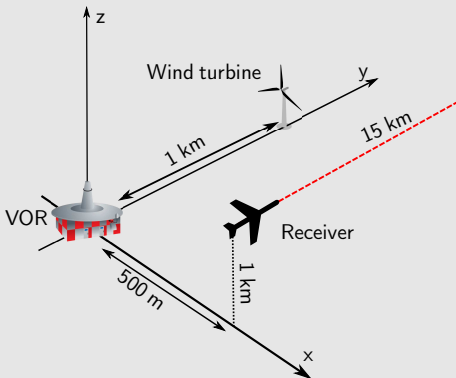


Figure 10 – Configuration

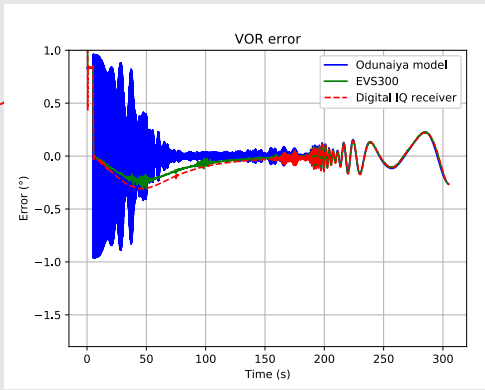


Figure 11 – Receivers responses

Analysis

- Good agreement between receiver model and calibration device

Confrontation from baseband IQ measurement : Results (2)

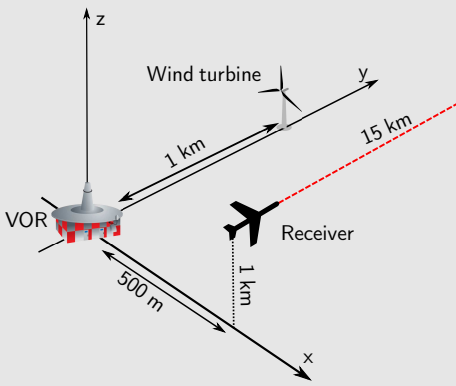


Figure 12 – Configuration

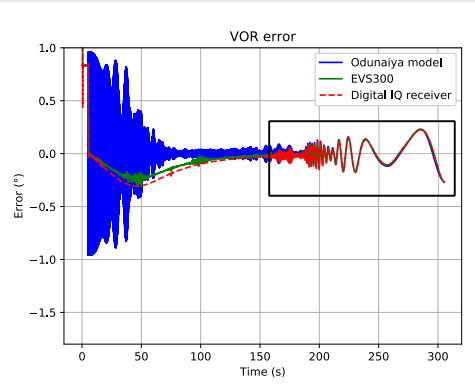


Figure 13 – Receivers responses

- ### Analysis
- Good agreement between receiver model and calibration device
 - When the multipath varies slowly \Rightarrow digital and calibration receiver response = static model response

Confrontation from baseband IQ measurement : Results (3)

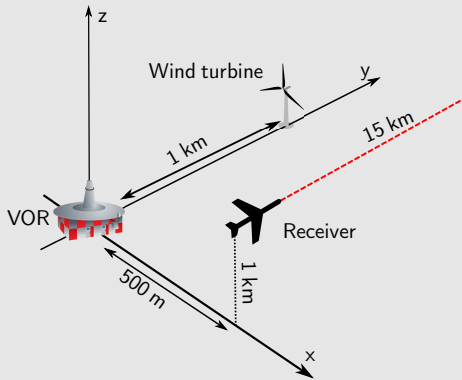


Figure 14 – Configuration

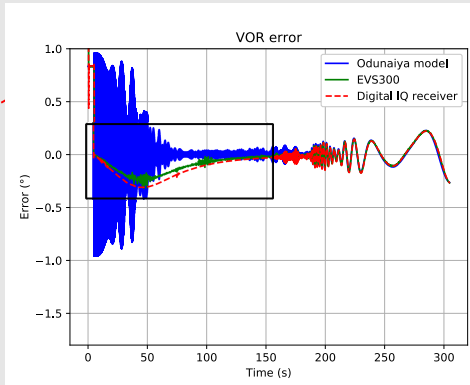


Figure 15 – Receivers responses

Analysis

- Good agreement between receiver model and calibration device
- When the multipath varies slowly \Rightarrow digital and calibration receiver response = static model response
- When the multipath varies quickly \Rightarrow digital and calibration receiver response \neq static model response \Rightarrow It is due to the dynamic effects of multipath

Confrontation from baseband IQ measurement : Results (4)

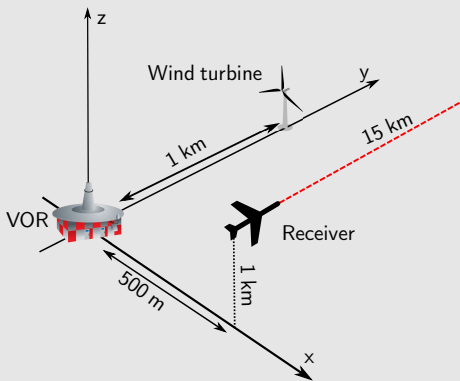


Figure 16 – Configuration

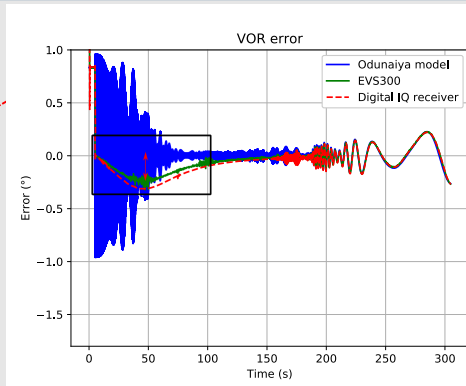


Figure 17 – Receivers responses

Analysis

- Good agreement between receiver model and calibration device
- When the multipath varies slowly \Rightarrow digital and calibration receiver response = static model response
- When the multipath varies quickly \Rightarrow digital and calibration receiver response \neq static model response \Rightarrow It is due to the dynamic effects of multipath
- Digital and calibration receiver response is shifted with respect to 0° between 5 s and 150 s \Rightarrow It is due to the group delay of receivers

Dynamic effects of multipath

Geometric criterion for dynamic sensitivity of VOR receiver

[Ben-Hassine et al., EuCAP 2020] : "Validity Domain of the Odunaiya Expression for Computing the Conventional VOR Multipath Error"

- Doppler frequency of multipath depends on the speed of the aircraft and its position with respect to the VOR station and wind turbine
- When the Doppler frequency δf_{mult} is not included in one of the two filter bandwidths of receiver (W_{30}, W_{DC}) \Rightarrow no multipath error
- Odunaiya model is considered invalid (red area) when

$$|\delta f_{mult}| > \frac{\min(W_{30}, W_{DC})}{2} \quad (1)$$

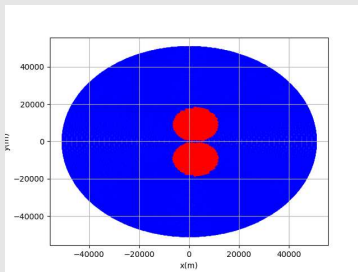


Figure 18 – Validity domain of the Odunaiya expression (in blue)

Plan

- 1 Introduction
- 2 VOR Receiver Model
- 3 Confrontation from VHF measurements
- 4 Confrontation from baseband IQ measurements
- 5 Conclusion

Conclusion

Conclusion

- Analysis of the digital IQ receiver model behaviour
 - Comparison with a calibration receiver (R&S EVS300) from laboratory measurements by processing a
 - VHF conventional signal for one canonical multipath
 - Baseband IQ conventional signal in complex realistic scenarios
 - Good agreement between results
- ⇒ Good confidence in the parameters of the digital IQ receiver model

Future works

- Validation with a Doppler VOR multipath
- Confrontation with other types of receivers (R&S EB200)