Using GNU Radio Companion to improve student understanding of signal processing theory through VHF Omni-Directional Range (VOR) signal demodulation

A. Blais, C. Morlaas

ENAC, Université de Toulouse, France

Abstract

The École Nationale de l'Aviation Civile (ENAC), the French Civil Aviation University, proposes a graduate engineer program with, among three others, a *major*, in Aeronautical and Space Telecommunications (SAT). This *major* is characterized by advanced theoretical courses in signal theory, signal processing, digital communications and navigation in particular. Some practicals are given to help the students understanding specific points in these courses. However, this scattered approach does not provide any hindsight on the interest and the usefulness of these courses, either independently nor together. This is the reason why these practicals are completed by a long project which proposes, as a global case of application, to demodulate a VHF Omni-Directional Range (VOR) signal. This paper details this long project, from its pedagogical approach to some interesting points of its implementation.

1 Introduction

The sometimes complex notions being taught in signal theory and signal processing courses need to find some practical realizations to be fully understood by the students. It is the objective of the long project described in this paper. Indeed, it proposes the demodulation of a VOR signal using the GNU Radio Companion (GRC) software. The simultaneous learning of this powerful software is an interesting aside of this project, even if it is not its primary goal. The signal in question is either received by mean of a DVB-T USB dongle (one is distributed per pair of students) or a synthetic one, generated in the course of the project by the students themselves. In the first part of this paper, a model of the VOR signal is presented. Then, the pedagogical approach selected by the teaching team is described. Two interesting technical points are adressed in the third part, to point out the signal processing challenges the students have to face. At last, a brief conclusion is drawn.

2 A VOR signal model

The VOR system is a navigation aid designed to give the angle, in relation to the magnetic north, to the aircraft from a ground radio beacon of known position. This is done with the help of an hybrid signal carrying several components. A noise-free time model of this signal [1], as seen by the receiver, is presented to the students:

$$e(t) = (1 + M(t)) \cos\left(2\pi f_0 t + \theta_0\right) \qquad (1)$$

$$\begin{aligned} M(t) = {} & 0.3 \cos\left(2\pi 30 t - \mathrm{QDR} + \theta_{30}\right) \\ & + 0,05 \, \mathrm{ident}(t) \cos\left(2\pi 1020 t + \theta_{1200}\right) \\ & + 0.3 \cos\left(2\pi 9960 t + \theta(t) + \theta_{9960}\right) \end{aligned} \qquad (2)$$

$$\begin{aligned} \theta(t) &= 16 \cdot 30 \cdot 2\pi \int_0^t \cos(2\pi 30 u + \theta_{30}) du \\ &= 16 \cdot \sin(2\pi 30 t + \theta_{30}) - 16 \cdot \sin(\theta_{30}) \end{aligned} \qquad (3)$$

with:

- $f_0 \in [108, 118]$ MHz, the carrier frequency,

- QDR the magnetic bearing from the station to the aircraft, in units of radian,

- $\mathrm{ident}(t)$ the identification signal of the VOR beacon (Morse code),

- θ_{30}, θ_{1200} and θ_{9960} random initial phases.

A graphical representation of the spectrum corresponding to the amplitude modulation $(1 + M(t))$, figure 1, is also shown to train the students to think in the frequency domain as well as in the time domain.
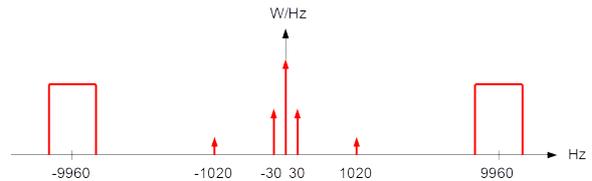

Figure 1: Schematic representation of the baseband spectrum of a VOR signal.

The models of the I & Q signals delivered by the DVB-T dongle are then derived from equations (1), (2) and (3)), after a short explanation of how this dongle works. This is an effective use of the complex envelope concept introduced in the digital communications course. These models are the starting point of the practical implementation.

3 The pedagogical approach

Strong guidelines are set to the students to support them toward the solution. Indeed, the project is split in four distinct and successive steps, each one improving gradually the skill and knowledge of the student:

1. The first step is an interactive implementation of a simple FM radio-broadcast receiver. This first SDR receiver serves as a presentation of the GRC GUI capabilities as well as a proof of the SDR concept for the students: it works!

2. The target of the second step is a more comprehensive handling of GRC and of the USB dongle. The students have to produce flow diagrams which read, display and record to a file the I & Q samples.

3. Then, to deepen the students understanding of the VOR signal structure, as well as to provide the future receiver with synthetic test signals, a I & Q VOR signal generator has to be implemented, component after component. The generated test signals are validated with the SDR receiver of the teaching team.

4. Finally, the VOR receiver itself has to be developed. Again, a component by component method is suggested to the students, so they can safely move towards a proper final design.

The project ends with a double evaluation: a one hour written examination and a test of reception of a real VOR signal with a QDR to decode. The latter test is realized by radiating a low power VOR signal in the room with the help of a Marconi 2030 signal generator.

4 Two specific technical points

The philosophy of this long project being to improve the understanding of the students in signal theory and signal processing, the use of high level blocks, like the `FM Demod` block, is forbidden. The students have then to understand the processings to be able to build them atomically. In this aspect, the two following ones are particularly interesting.

4.1 The frequency demodulation

Figure 2 illustrates the demodulation principle the students not only have to implement, but also to understand! The calculation of the value of the delay is always an instructive brainstorm.
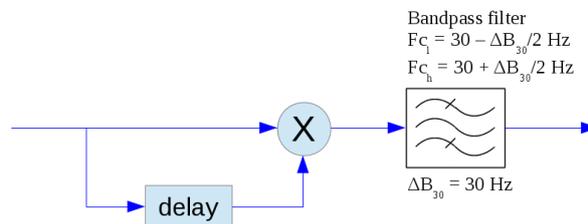

Figure 2: Synoptic view of the FM demodulator.

4.2 The phase comparator

The phase comparator, needed to extract the QDR, the value of interest, is an opportunity to introduce the students with the principle of the `Hier` block. They are asked to embedded this phase comparator in a dedicated `Hier` block, to be tested and validated independently from the main flow diagram. Figure 3 displays a possible implementation for this phase comparator `Hier` block.
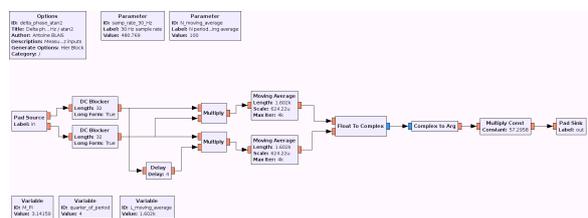

Figure 3: Flow diagram of the phase comparator

5 Conclusion

It is the third year this long project is given. The teaching team has observed each time the benefits of this materialization of the theoretical notions taught during the related courses. The knowledge and skill of the students are clearly improved as well as their hindsight on the covered topics.

References

[1] Subdivision Radionavigation conventionnelle et par satellite. VOR Généralités. Technical report, École Nationale de l'Aviation Civile, 2010.