GNURadio as a digital signal processing environment: application to acoustic wireless sensor measurement and time & frequency analysis of periodic signals

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Abstract—The flexibility, reconfigurability and stability of software defined radio yield an attractive alternative to the analog strategy of probing acoustic transducers acting as passive sensors probed through a wireless link or to phase noise characterization of oscillators. However, developing processing blocks is a time consuming activity, yet metrology applications require a dedicated understanding of each processing step. We consider GNURadio as a means of exploiting opensource software as an optimum tradeoff between software re-usability yet compatible with an audit for assessing performance. This signal processing environment is demonstrated on two practical examples, FMCW probing of acoustic delay lines acting as sensors, and quartz tuning fork characterization. Both examples are considered as introductory setups for training and teaching yet a suitable environment for research activities.

I. INTRODUCTION

Digital signal processing has been identified as a significant improvement over analog signal processing for a number of reasons [1], [2], including stability, flexibility and accuracy. Respectively, digital signal processing is not prone to component aging or drift over time; is reconfigurable in order to update algorithms or parameters in order to perform new functionalities on a given hardware; and provides a pre-defined, quantitative computation accuracy given the size of the handled datasets. Digital signal processing is nowadays ubiquitous and the mostly infinite computational power available yields to the trend of Software Defined Radio [3], in which general purpose radiofrequency source and sampling hardware is used for software processing of the recorded data for multiple application on a given experimental setup. Although processing power has been increasing continuously, the extensive bandwidth needed for radiofrequency (RF) sampling often remains beyond the general purpose hardware. On the other hand, most RF signal are narrowband and do not require full bandwidth sampling, so a common trend is to use an analog frontend with an amplifier and a mixer with a local oscillator to provide a zero-intermediate frequency (IF) configuration. We consider here the use of such a configuration in the context of time and frequency metrology signal processing, and most significantly consider the software environment needed to implement the associated processing algorithm, both from application and a teaching considerations since the skills for applying these concepts are mostly lacking.

II. FMCW RADAR FOR PASSIVE WIRELESS SENSOR MONITORING

Acoustic transducers [4] have been demonstrated to be relevant alternatives to silicon-based radiofrequency identification tags (RFID) when harsh environments (temperatures above CMOS operating range) or long interrogation ranges (no threshold on the received power in the case of piezoelectric substrate) are needed. By patterning electrodes on single crystal substrates, a delay line configuration aims at providing a simple means to convert the incoming electromagnetic signal to a mechanical wave whose propagation velocity on the surface of the substrate is dependent on the physical property under investigation [5]. Through direct piezoelectric effect, the pulse reflected on a mirror patterned on the substrate generates a returned electromagnetic signal: the purpose of the readout unit is to allow for a measurement of this time of flight in order to recover the physical quantity value [6].

A classical pulsed-mode RADAR approach requires large measurement bandwidths B in order to achieve time resolution $1/B$: typical pulse widths and maximum time of flight durations are respectively 100 ns and 5 μs, so that $B > 10$ MS/s is needed. Although the pulsed mode, wideband RADAR approach provides some significant range and measurement speed advantages, a simpler approach has been favored in the literature through the use of the frequency-modulated continuous wave (FMCW) RADAR approach [7]. In the latter method, a local oscillator frequency f is linearly swept along a bandwidth B within the bandpass function of the acoustic delay line. The time delayed returned τ signal is mixed and low pass filtered with the local oscillator, so that a beat signal $\Delta f(\tau) = f(t) - f(t + \tau)$ is recorded after removal of the carrier. The resulting architecture is simple and only requires low frequency sampling rates, but also introduces multiple free parameters which are best tested in a software defined radio approach. Among the parameters are the central operating frequency f and the sweep rate T: $\Delta f(\tau)/\tau = B/T$ since the frequency band B is swept linearly over a duration T.

Recently, a tutorial has been presented on the MIT OpenCourseWare web site [8] demonstrating a basic FMCW approach: this hardware platform is used as the starting point of this experiment, although the linear RF oscillator sweep and recording a no longer performed by dedicated hardware but by a personal computer sound card running GNURadio (http:

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Table of Contents Gnuradio As A Digital Signal Processing Environment

1. Understanding the eBook Gnuradio As A Digital Signal Processing Environment
    - The Rise of Digital Reading Gnuradio As A Digital Signal Processing Environment
    - Advantages of eBooks Over Traditional Books
2. Identifying Gnuradio As A Digital Signal Processing Environment
    - Exploring Different Genres
    - Considering Fiction vs. Non-Fiction
    - Determining Your Reading Goals
3. Choosing the Right eBook Platform
    - Popular eBook Platforms
    - Features to Look for in an Gnuradio As A Digital Signal Processing Environment
    - User-Friendly Interface
4. Exploring eBook Recommendations from Gnuradio As A Digital Signal Processing Environment
    - Personalized Recommendations
    - Gnuradio As A Digital Signal Processing Environment User Reviews and Ratings
    - Gnuradio As A Digital Signal Processing Environment and Bestseller Lists
5. Accessing Gnuradio As A Digital Signal Processing Environment Free and Paid eBooks
    - Gnuradio As A Digital Signal Processing Environment Public Domain eBooks
    - Gnuradio As A Digital Signal Processing Environment eBook Subscription Services
    - Gnuradio As A Digital Signal Processing Environment Budget-Friendly Options
6. Navigating Gnuradio As A Digital Signal Processing Environment eBook Formats

- ePub, PDF, MOBI, and More
- Gnuradio As A Digital Signal Processing Environment Compatibility with Devices
- Gnuradio As A Digital Signal Processing Environment Enhanced eBook Features

7. Enhancing Your Reading Experience
    - Adjustable Fonts and Text Sizes of Gnuradio As A Digital Signal Processing Environment
    - Highlighting and Note-Taking Gnuradio As A Digital Signal Processing Environment
    - Interactive Elements Gnuradio As A Digital Signal Processing Environment

8. Staying Engaged with Gnuradio As A Digital Signal Processing Environment
    - Joining Online Reading Communities
    - Participating in Virtual Book Clubs
    - Following Authors and Publishers Gnuradio As A Digital Signal Processing Environment

9. Balancing eBooks and Physical Books Gnuradio As A Digital Signal Processing Environment
    - Benefits of a Digital Library
    - Creating a Diverse Reading Collection Gnuradio As A Digital Signal Processing Environment

10. Overcoming Reading Challenges
    - Dealing with Digital Eye Strain
    - Minimizing Distractions
    - Managing Screen Time

11. Cultivating a Reading Routine Gnuradio As A Digital Signal Processing Environment
    - Setting Reading Goals Gnuradio As A Digital Signal Processing Environment
    - Carving Out Dedicated Reading Time

12. Sourcing Reliable Information of Gnuradio As A Digital Signal Processing Environment
    - Fact-Checking eBook Content of Gnuradio As A Digital Signal Processing Environment
    - Distinguishing Credible Sources

13. Promoting Lifelong Learning
    - Utilizing eBooks for Skill Development
    - Exploring Educational eBooks

14. Embracing eBook Trends
    - Integration of Multimedia Elements
    - Interactive and Gamified eBooks

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