AC 2010-867: DIVERSITY RECEIVER FOR DIGITAL RADIO MONDIALE - A MULTI-YEAR DESIGN PROJECT

Paul Leiffer, LeTourneau University

PAUL R. LEIFFER is a professor in the Engineering and Engineering Technology Division at LeTourneau University, where he has taught since 1975. He received his B.S.E.E. from the State University of New York at Buffalo and his M.S. and Ph.D. degrees from Drexel University. Prior to joining the faculty at LeTourneau, he was involved in cardiac cell research at the University of Kansas Medical Center. His professional interests include digital signal processing, biomedical engineering, and appropriate technology.

Joonwan Kim, LeTourneau University

JOONWAN KIM is an associate profesor in the Engineering Department at LeTourneau University, where he has taught since 2003. He received his B.S. degree from Daegu University in South Korea and his M.S. and Ph.D. degrees from the University of Alabama in Huntsville. Dr. Kim's interest areas include speech processing and adaptive noise filtering.

R. William Graff, LeTourneau University

R. WILLIAM GRAFF is a professor in the Engineering and Engineering Technology Division at LeTourneau University, where he has taught since 1975. He received his B.S., M.S., and PH.D. degrees from Purdue University in electrical engineering. Prior to joining the faculty at LeTourneau, he was assistant professor of electrical engineering at Drexel University for six years, and at Wilkes College for two years. His professional interests include antennas, microwaves, plasmas, and ethics.

Don Willcox, LeTourneau University

DON WILLCOX is a senior at LeTourneau University, majoring in Electrical Engineering and Engineering Physics.

© American Society for Engineering Education, 2010

Diversity Receiver for Digital Radio Mondiale – A Multi-Year Design Project

Introduction

In nations where the Internet is a rare luxury, radio remains the most efficient way to spread important information to the majority of the populace. Non-profit radio pioneer HCJB, "The Voice of the Andes," currently works at developing new transmitters and receivers from their technology center in Elkhart, Indiana. HCJB has sponsored the development of many broadcast stations in these less-developed countries, including parts of Africa and Indonesia. Citizens tune in to hear essential public health information, directions for disaster/relief aid, as well as "normal" programming including music, talk shows, and Christian programs. For many listeners this may be their only window to the outside world.

Unfortunately, due to the de-centralized and de-urbanized nature of these less-developed countries, many listeners live in isolated communities far from the main cities where the radio studios reside. Transmitting content to these remote listeners and their local radio stations is a major challenge for broadcasters. The preferred method of broadcast is FM, which provides good audio quality but only over short distances. One strategy used by some broadcasters is to "chain" FM repeater links together, stretching the effective transmission range of FM but losing quality in the process. AM radio provides the necessary range to cover entire countries, but its quality suffers in comparison to FM. Furthermore, in many regions, long-range AM transmissions are also hampered by signal degradation brought about by changes in the ionosphere.

Digital Radio Mondiale (DRM) is a European digital radio standard designed specifically for shortwave AM broadcasts, including those in the tropical-band frequency range. DRM allows broadcasters to transmit FM-quality audio over AM-grade ranges, and as such, is of particular interest to non-profit broadcasters such as HCJB.

DRM Background

The Digital Radio Mondiale system was developed by a consortium of over seventy broadcasters and broadcast organizations to satisfy the need for a digital broadcast standard for frequency bands below 30 MHz. [1, 2] It was approved by the European Telecommunication Standards Institute in 2001 and has been extended to frequencies up to 174 MHz. [3,4] A number of broadcasters began digital transmission in 2003, and seven DRM receivers were developed that year. [5]

An advantage of DRM over analog radio, in addition to reception quality, is its ability to transmit both audio and data streams. DRM makes use of QAM mapping and Coded Orthogonal Frequency Division Multiplexing (COFDM), which utilizes a convolutional forward error-correcting code with a set of low-bitrate signals at closely spaced frequencies. [6]

DRM Receiver as a Senior Design Project

In 2007 engineers from HCJB discussed with our faculty the possibility of working with them on a project to develop a receiver which could be used as part of a studio-transmitter rebroadcast link, in which DRM signals from the primary broadcast would be received and demodulated for local rebroadcast. For the past three years our senior design students have worked on a project to design a DRM diversity receiver to HCJB's specifications, with funding support from Rockwell Collins Inc. The receiver itself is broken down into five modules: Preselector, Variable Gain Amplifier/Analog-Digital Converter, Digital Downconverter, USB interface, and software DRM demodulator. A variety of skills across several major engineering and computer disciplines were required in such areas as analog filter design, PCB layout, VHDL programming, digital signal processing, spectral analysis, Fast Fourier Transforms, USB communication and C++ programming. These skills are drawn from majors in Electrical Engineering, Computer Engineering, and Computer Science/Engineering. Collaboration between students, faculty, clients, and engineering support has broadened students' grasp of the design process and strengthened our relationships with industry leaders.

From the initial discussions it was obvious that the DRM receiver would be a multi-year project, involving students from various disciplines. The project is being completed in the third year of its run. Each year's team had specific goals, as shown-

Year One: Learn the basic theory behind digital broadcasting and the parts needed to complete a DRM receiver
Nail down the system specifications for the entire receiver
Develop the preselector and the basic software for the downconverter

Year Two: Refine the hardware, complete the software, and accomplish single channel demodulation

Year Three: Complete the Software demodulation for multiple channels and implement phase diversity

Project Organization

At LeTourneau University, all engineering students participate in a two-semester design project at the senior level. Design projects are team-oriented and require students to design, implement, and verify their solution to an engineering problem: this process draws upon both the students' cumulative knowledge of their engineering field and techniques that require independent learning. Teams are evaluated based on the thoroughness of their planning and design process and their success in achieving project goals.

Senior Design student teams are assembled at the start of the fall semester from students from all concentrations. Project details are announced, along with the mix of skills needed, and students select their top choices. From these choices, the faculty assembles the year's teams. Each design team must have a faculty sponsor, two faculty advisors, with the possibility of outside sponsors or clients.

Year One team consisted of two students from the electrical engineering concentration, one student from computer engineering, and one computer science major.

Year Two team had four students from the computer engineering concentration and one from electrical engineering.

Year Three team was made up of four students from the electrical engineering concentration and one Computer Science and Engineering major.

HCJB supplied the project goals and specifications, and gave design advice to the team. Each week the student team held a phone conference with the HCJB engineers.

Managing a three-year design project effectively requires careful goal-setting and meticulous planning. Over each of the three years of the DRM design project, three senior teams learned to evaluate the design problem they faced, propose tentative solutions, establish objectives, and set goals. The student team leaders consolidated the team planning process into a year-long Gantt chart depicting the task-by-task deadlines for each member of the team and each project module. Students learned to plan project tasks in order to minimize resource conflicts and remain within the project's yearly budget. In years two and three the year goals were broken into three phases of approximately three months each. The teams' planning processes were then evaluated by faculty sponsors assigned to the DRM project for feasibility, thoroughness, and efficiency.

Receiver Design

Over the three years of the project the LeTourneau DRM team, in conjunction with engineers from HCJB Global, designed a modularized DRM receiver, as shown in figure 1.

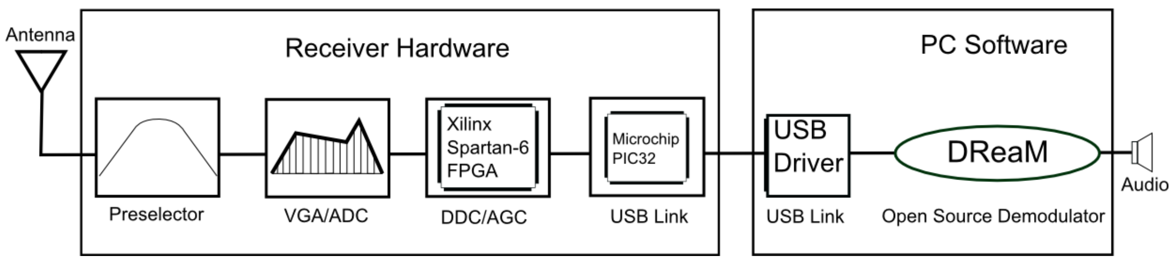

Figure 1. DRM Receiver

The receiver consists of a hardware component and a software component. The receiver hardware interfaces with a standard coaxial antenna input, converts the radio frequency signal to baseband, and transfers the digitized signal to a computer over a USB 2.0 connection. The receiver software running on the host computer then extracts the audio stream from the digital radio signal using a modified version of DReaM, open source demodulation software for DRM. Each of the hardware and software modules required a diverse array of skills from the electrical engineering and computer science/engineering programs.
The hardware component of the project begins with the preselector, a passive bandpass filter with a passband of 3.2-30 MHz. The preselector functions to limit reception to only the desired frequency range and to improve the receiver's out-of-band overload resilience. Preselector development required students to apply analog filter design techniques and careful printed circuit board (PCB) layout and assembly procedures in order to limit extraneous noise. In verifying the circuit's performance, students characterized the transmission and reflection characteristics of the circuit using a vector network analyzer and redesigned the circuit to meet specifications as necessary. Preselector design therefore emphasized electrical engineering skills.

The variable gain amplifier (VGA) provides the receiver with a high dynamic range and the analog-to-digital converter (ADC) module digitizes the analog radio signal for processing by the subsequent receiver stages. Development of the VGA/ADC module required students to select commercial integrated circuits according to system specifications and design a PCB layout that limited noise and facilitated integration with the rest of the system's hardware. Electrical/computer engineering students then tested the PCB to verify that it functioned within its specifications.

A field-programmable gate array (FPGA) then performs digital downconversion (DDC), converting the radiofrequency signal to 0 Hz baseband frequency. Digital filtering and automatic gain control programs on the FPGA then decimate the signal's bitrate and eliminate noise. The FPGA sends the digital data in packets to a microcontroller dedicated to USB communication. Developing the FPGA's firmware required programming skills in VHDL (Very High-Speed Integrated-Circuit Hardware Description Language) and an understanding of digital filters, frequency-domain representations of signals, and precision hardware timing. This module thus emphasized students' computer and electrical engineering abilities.

The USB 2.0 link between the FPGA and the computer comprises hardware and software with both firmware development on a microcontroller and driver development for Windows and Linux. The microcontroller receives data packets from the FPGA, buffers them in memory, and transmits them to the computer according to the USB 2.0 specification. Furthermore, the microcontroller is responsible for transmitting user commands from the computer to the FPGA. Electrical engineering students developing the USB interface applied their knowledge of C programming, microcontroller hardware, the USB 2.0 specification, and cross-platform driver customization.

Students then concluded the project's hardware design by designing a custom PCB system board that integrated all hardware components of the receiver: preselector, VGA/ADC, FPGA, and microcontroller. This extensive board design required electrical and computer engineering students to familiarize themselves with commercial schematic and layout software as well as the testing and redesign stages of hardware development. This integrated system board is the project's client deliverable

Software development in addition to custom driver programming was required. The open-source DReaM demodulation software for DRM required student modification in order to accept data input over a USB connection and implement a multithreaded diversity combining algorithm to improve signal quality and reliability. DReaM development required C++ programming skills and an understanding of the Maximal Ratio Combining diversity algorithm, highlighting the skills of computer science/engineering students.

Project Maintenance

Ongoing evaluation of the team's progress makes just as important a contribution to the project's success as clear organization. The design team and faculty sponsors monitored the team's status regularly in several ways, and weekly conferences were held with engineers from HCJB Global. The team's frequent and open communication not only with each other but also with faculty and clients allowed them to quickly address design changes and unforeseen problems.

The senior design team maintained itself by an internal hierarchy: one team leader was responsible not only for project planning and organization but also for ensuring that all team members worked as effectively as possible in adherence to the project's schedule. Also, all individual team members filled out a daily work summary throughout each week in order to keep track of the hours they spent on the project and the work they accomplished. Furthermore, the team met at a minimum of twice per week to review the progress, achievements, and difficulties of each team member. These meetings allowed members to find solutions collaboratively even when each member had an individualized task.

Faculty sponsors for the DRM project provided a higher level of maintenance than it was possible for the team leader to provide. The team had two faculty sponsors at a minimum, one of them also serving as the project director. Faculty sponsors were involved in the initial long-term project planning and provided the team with ongoing technical or organizational advice as needed during weekly meetings with the entire design team. On a weekly basis, the team discussed the project's progress, difficulties, or changes to the design approach with the faculty sponsors. Additionally, the project director met with the team leader at the start of each week in order to discuss the week's activities, plan team events, and monitor the team's progress toward its long-term goals. This high level of faculty involvement with the ongoing project maintenance assisted the team in adapting to the requirements of the senior design project.

Per-semester team conferences with engineers from the project's sponsor, Rockwell Collins, provided the team an opportunity to present the project's progress, status, and projected goals to industry professionals. Rockwell Collins engineers offered the team general advice and oversight: this gave the students an opportunity to participate in a team-sponsor relationship and build relationships with Rockwell Collins.

Moreover, frequent team conferences with engineers from HCJB Global Technologies assisted the team in identifying potential problems and finding solutions. At a minimum of once per week, the student design team discussed with HCJB the project's progress and any problems they encountered during the previous week. Additionally, individual team members teleconferenced with client engineers throughout each week as needed. The ongoing interaction between the design team and client engineers helped the team to maintain the project within the target specifications and gave the team members opportunities to learn from experienced radio engineers.

Educational Benefits of the DRM Project

One of the most significant benefits of the DRM project both to students and to the electrical/computer engineering programs at LeTourneau University is access to new and expensive equipment that would not otherwise be available. The team's industrial funding permitted it to purchase a new Mixed Signal Oscilloscope, Spectrum Analyzer, Vector Network Analyzer, test hardware, and development software. Although this equipment was exclusively used by the DRM team during the project, the equipment is now available for use by electrical and computer engineering students to help them become familiar with current technology and test methods.

Additionally, the DRM team had the opportunity to develop hardware and software for reception of the current Digital Radio Mondiale radio standard. The ability to collaborate closely with industry professionals on a project designed for a relatively new communications standard is enriching not only to students' education but also to their careers. Furthermore, many of the hardware and software design abilities the students gained will be useful in applications beyond the Digital Radio Mondiale project, especially as communications technology becomes increasingly software-driven. Ultimately, however, one of the most important contributions of such a design project to engineering education is the practice that students gain with the planning, management, and execution of a complex project.

When a project is extended over multiple years with tasks divided among different teams, not every student will have the same experience. The first year team, for example, started from scratch and needed significant assistance to grasp the overall project. While not every student shares the same experience, by proper direction every student can meet the course goals. Following printed course guidelines every student team must (1) document project specifications, (2) define deliverables, (3) locate relevant standards, (4) apply design process steps, (5) produce and test a prototype, (6) track with milestones, (7) track with a budget, and (8) document the results. Senior design project teams comprised of students from all our engineering concentrations should meet identical outcomes and follow identical reporting schedules.

Lessons learned

1. Since most real-world/ industrial projects take over a year to complete, multi-year senior design projects are certainly realistic. Final project reports become valuable background and startup documents for the next year's team.
2. Design projects with the breadth of the DRM receiver require multidisciplinary teams. Our senior design sequence was restructured a few years ago to become a general course for all concentrations, with most projects being interdisciplinary.
3. For a multi-year project, the presence of junior level members is critical. These students participate in the project, learn key concepts, and can carry this information on into the following year's team. Some junior members have spent a spring break or part of a summer directly working with the engineers at HCJB. In addition, juniors become the "cheer-leaders" for the project and are very influential in recruiting the next fall's team. There could be an advantage to including sophomore students on the team to see the "big picture" over three years.
4. Effective student team leadership is essential to the success of the team. We have watched some of our team leaders grow into very effective project managers.
5. Regular communication with clients and industry volunteers is a key to a successful multi-year project.
6. A continuing question arises with regard to design projects: How much should the faculty intervene if they see students, because of their inexperience, making bad design choices? Our conclusion has been that it depends on the nature of the project. If the project is being carried for an industrial client or under a research grant, the faculty director should offer strong direction so that the project succeeds. If the project is student-oriented, such as an SAE competition, students may more often learn from their mistakes. The best compromise seems to be scheduling design reviews with industry professionals who question the students on their design choices.

Conclusions

A multi-year student design project for the development of a Digital Radio Mondiale receiver has been presented. The project combined current technology, an international application, and industry collaboration in a complex project for electrical and computer engineering students. The project's organization, maintenance, and industry support all contributed to the student design experience, and it enhanced not only the engineering proficiency of the teams involved but also the quality of the electrical and computer engineering departments at LeTourneau University.

Advantages to students and to the engineering program have included access to new technologies and test equipment, career-building interactions with industry professionals, and development of student communication skills.

Bibliography

1. Jackson, P., "DRM- Progress on the Receiver Front," *EBU Technical Review*, January 2003.
2. Poole, I. "What exactly is . . . Digital Radio Mondiale?," *Communications Engineer*, vol.2, no.2, pp. 44- 45, April-May 2004.
3. DRM website: http://www.drm.org
4. ETSI TS 101 980 v1.1.1 (2001-09), Digital Radio Mondiale (DRM); System Specification.
5. Jackson, op. cit.
6. Stott, Jonathan. "DRM – Key Technical Features," *EBU Technical*, Tech. Review 286, March 2001.