A Software Defined Radio Test-bed for WLAN Front Ends

Vincent Arkesteijn[1], Roel Schiphorst[2], Fokke Hoeksema[2],
Eric Klumperink[1], Bram Nauta[1], Kees Slump[2]
[1]Integrated Circuit Design Group, MESA$^+$ Institute
[2]Laboratory of Signals and Systems, CTIT Institute
University of Twente, Department of Electrical Engineering
P.O. box 217 - 7500 AE Enschede - The Netherlands
E-mail: {`v.j.arkesteijn,r.schiphorst,f.w.hoeksema,`
`e.a.m.klumperink,b.nauta,c.h.slump`}`@el.utwente.nl`

Abstract—**In our *Software Defined Radio* (SDR) project we aim at combining two different types of standards, Bluetooth and HiperLAN/2 on one common flexible hardware platform. The HiperLAN/2 hardware is that complex compared to the Bluetooth hardware, that Bluetooth capability may be added to the HiperLAN/2 platform at limited cost. The question is how to do this.**

In this paper we first describe the radio front-end functions and their implementation. Subsequently the test-bed that will assist us in building the hardware platform is described. We present the method by which we use the HiperLAN/2 front-end for Bluetooth reception purposes. Our system consists of three parts: analog signal processing, digital channel selection and digital demodulation. The analog processing function is capable of reception of both standards. The demodulation function and channel selection function are implemented in two separate software programs (one for each standard) that allow the exploration of different design alternatives and the assessment of computational cost of the receiver.

keywords: Software Defined Radio, HiperLAN/2, Bluetooth, Physical Layer, Radio Frequency, Channel Selection, Demodulation.

I. INTRODUCTION

In our SDR project we aim at combining two different types of standards –Bluetooth and HiperLAN/2– on one common hardware platform. HiperLAN/2 is a high-speed Wireless LAN (WLAN) standard (e.g. [3] and [4]), whereas Bluetooth is a low-cost and low-speed Personal Area Network (PAN) standard ([8]). As is illustrated in table I the standards differ in several aspects and pose an interesting challenge for an SDR platform.

We focus on the radio front-end of a receiver, so from antenna (Radio Frequency (RF) signal) till and including demodulator (raw bits); see figure 1.

TABLE I
BLUETOOTH & HIPERLAN/2 PARAMETERS.

	Bluetooth	HiperLAN/2
System	PAN	WLAN
Frequency Band	2.4-2.4835 GHz	5.150-5.300 GHz, 5.470-5.725 GHz
Access Method	CDMA	TDMA
Duplex Method	TDD	TDD
Modulation Type	GFSK	OFDM
Max. Data Rate	1 Mbps	54 Mbps
Channel Spacing	1 MHz	20 MHz
Max Power Peak	100 mW	200 mW - 1 W

A. Views on Software Radio

In our opinion SDR is an implementation technology in which two lines of thinking can be distinguished: the first trend is to implement radio algorithms using a general purpose processor; the second trend is to provide flexibility and reconfigurability to hardware platforms. In our project we follow the second line of thinking, however in a particular way: the HiperLAN/2 hardware is that complex compared to the Bluetooth hardware, that Bluetooth capability may be added to the HiperLAN/2 platform at limited cost. So it is not the demand for flexibility (one front-end for all signals) that motivates us, but the idea of providing added functionality nearly “for free”.

From a software-radio perspective the issues are to determine which functions can be identical for both standards, which functions are different (and should be switchable at the time instant a particular standard is selected) and which functions can be parameterizable (identical functions with parameters depending on the selected standard).

B. System Overview

In this paper, we present a method by which a HiperLAN/2 front-end can be used for Bluetooth reception purposes. We distinguish analog signal processing, digital channel selection and digital demodulation functions, see figure 2. In section V our test-bed is presented.

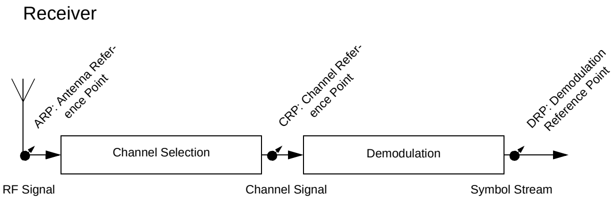

Fig. 1. Front-end functions.

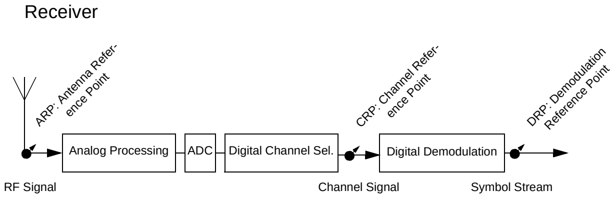

Fig. 2. Analog-digital partitioning.

II. ANALOG SIGNAL PROCESSING

As described in the introduction, our idea was to start with a HiperLAN/2 receiver, and change it just enough to accomodate Bluetooth reception as well.

A possible block schematic for the analog part of a HiperLAN/2 receiver is shown in figure 3. This setup is known as a zero-IF or direct conversion receiver, because the incoming radio-frequency (RF) signal is converted directly to baseband by the mixer (see for instance [6]).

In a normal, single standard HiperLAN/2 receiver, the first filter (between the antenna and the first amplifier) is just wide enough to pass the whole HiperLAN/2 band (from 5.1 to 5.7 GHz). Clearly, this is a problem for Bluetooth signals, that are between 2.4 and 2.48 GHz.

One very simple solution would be to widen this filter, to let it pass all signals between 2.4 and 5.7 GHz. Unfortunately, this will not work. In this wide band many unwanted signals will exist, some potentially very strong. Because of non-linearity in the receiver, these signals can result in interference with the wanted signal.

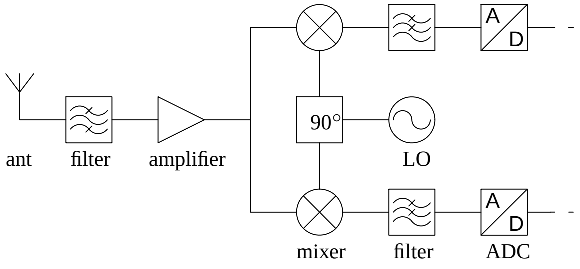

Fig. 3. Analog part of a single-standard zero-IF receiver

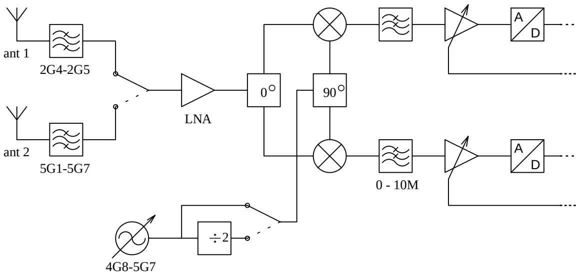

Fig. 4. Analog part of a combined HiperLAN/2 / Bluetooth receiver

To solve this problem, two filters with a relatively small bandwidth are required. Their pass bands will be from 2.4 to 2.48 and from 5.15 to 5.725 GHz, respectively. A switch will be used to select between these two filters. The resulting block schematic is shown in figure 4.

After these two filters, the signals will be amplified. Then, quadrature mixing is used to mix the signals down to baseband, generating in-phase and quadrature signals.

The local oscillator (LO) determines at which frequency signals are received. For HiperLAN/2 it needs a frequency range of around 5.1 till 5.7 GHz, while for Bluetooth a frequency range of approximately 2.4 till 2.5 GHz is required. Because a local oscillator that spans the entire frequency range from 2.4 GHz to 5.7 GHz is impractical, it was decided to use a frequency divider.

The LO has a step size of 20 MHz. This equals the channel spacing of HiperLAN/2. For Bluetooth, due to the frequency divider, the step size is 10 MHz. Because channel spacing for Bluetooth is 1 MHz, further mixing and channel selection has to be performed digitally (see section III).

One HiperLAN/2 channel is 20 MHz wide, so after quadrature mixing, two low pass filters with a bandwidth of 10 MHz are needed. Bluetooth signals are much narrower (1 MHz bandwidth), so further filtering has to be done digitally (again, see section III). An other option would for instance have been to use tunable analog filters, as described in [1].

After the low-pass filtering, the signals are sampled and quantized by the analog-to-digital converter (ADC).

III. DIGITAL CHANNEL SELECTION

The (analog) oscillator frequency is adjustable in steps of 10 MHz in order to follow the Bluetooth hopping pattern. In each hop-period, a so-called “chunk” of bandwidth of width $B_c = 10$ MHz is mixed towards zero. The wanted channel is present somewhere in the chunk. So, after quadrature mixing, the relevant channels for further processing are in a (zero-IF) chunk[1] of $0 \leq f \leq B_c = 10$ MHz. In the digital domain a *particular* Bluetooth channel has to be selected and mixed toward a frequency suitable for demodulation purposes (see section IV).

For Bluetooth signal reception, we mix at the low-side of the required 10 MHz chunk, while for HiperLAN/2 the mixing frequency f_0 can be chosen in the centre of the required 20 MHz band. In figure 5, the effects of central-band and low-band modulation are shown. In the picture, power spectra are graphically depicted for, from top to bottom, the bandpass signal $x(t)$, its analytical signal $\overset{o}{x}(t)$, its complex envelope $\tilde{x}(t)$ and the in-phase and quadrature signals $x_c(t)$ and $x_s(t)$ (following the notation in [2]).

Choosing 10 MHz chunks enables both the (analog) lowpass filter for a Bluetooth signal and for a HiperLAN/2 signal to be of equal width, see figure 5. The result of the (analog) mixing function is a low-IF Bluetooth signal (in a zero-IF chunk) and a zero-IF HiperLAN/2 signal.

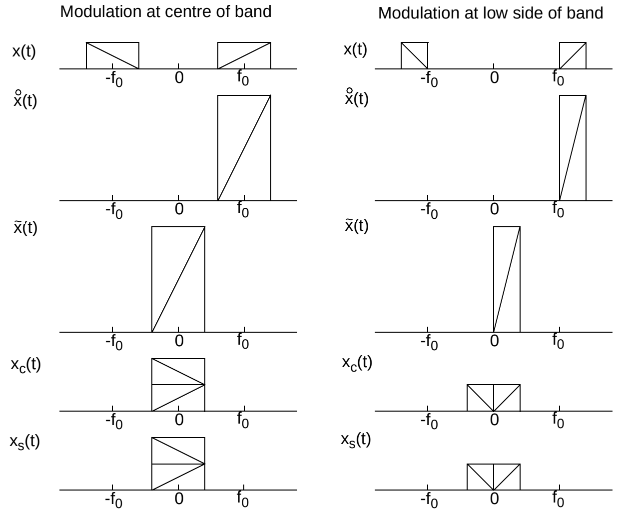

Fig. 5. Central-band and low-band modulation of a bandpass-signal $x(t)$. Blocks represent power spectra.

The digital channel selection function is to be switchable between HiperLAN/2 reception and Bluetooth reception. For Bluetooth an individual channel has to be selected out of the zero-IF chunk and to be mixed to a low-IF (2 MHz) band for demodulation purposes. Currently a narrow-band filter followed by a Numerical Controlled Oscillator (NCO) are designed. The requirements for the digital channel selection function were presented in [5]. For HiperLAN/2 post-ADC filtering is performed by a digital FIR filter. For both Bluetooth and HiperLAN/2 rate conversion takes place from the ADC sampling rate to the demodulator rate.

So,while the digital filters for Bluetooth and HiperLAN/2 reception need to be selected by a switch, the analog filter and ADC are designed to be identical for reception of both standards.

IV. DIGITAL DEMODULATION

For digital demodulation we use captured signal samples (see section V) as input for two separate MATLAB/Simulink simulation programs: one for Bluetooth demodulation and one for HiperLAN/2 demodulation.

A. HiperLAN/2 Demodulation

The structure of an OFDM receiver consists of three basic parts:

- preamble removal
- FFT
- QAM demodulator

A HiperLAN/2 symbol has a duration of $4\ \mu s$ (80 samples at a clock rate of 20 MHz). The first 16 samples are a copy of the last 16 samples. So synchronization of an OFDM symbol can be achieved by using a correlator, which correlates the beginning of an OFDM symbol with the end. The preamble removal part fulfills this function. This part is one of the most sensitive/critical parts of a HiperLAN/2 receiver. After preamble removal a 64-points FFT is carried out which translates the phase and amplitude of the 52 carriers into 52 complex symbols. These symbols are QAM demodulated and the symbol-to-bits conversion is performed in the QAM demodulator. A realistic OFDM receiver must also perform equalization, phase offset correction and frequency correction. In our test bed we focus, for now, only on the three basic parts, mentioned above.

B. Bluetooth Demodulation

Bluetooth demodulation can be divided into two parts:

- demodulator
- symbol decision

The demodulation function converts the incoming Gaussian Frequency Shift Keying (GFSK) signal into a Non-Return-to-Zero (NRZ) signal. This can be seen as the digital equivalent of an analog demodulator. The second part, the symbol decision determines which bit was transmitted. For the demodulator we use an FM discrimination algorithm, as its processing requirements are less than for a phase-shift algorithm, while performance loss is only about 1.5 dB [7]. Furthermore, as the FM discrimination method requires a low IF signal, the output of the channel selection is real which is expected to be more computational efficient than a complex output. Symbol decision is

---

[1] A zero Intermediate Frequency (IF) chunk is also known as a baseband chunk.

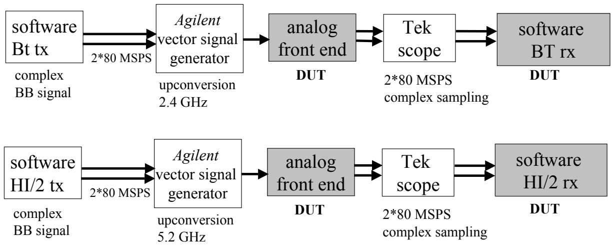

Fig. 6. Test-bed configuration.

performed by single sample decision (and using the optimal decision moment).

V. TEST-BED CONFIGURATION

In order to prove the validity of our ideas, a test-bed is designed and implemented, see figure 6. The test-bed consists of two separate MATLAB/Simulink programs for HiperLAN/2 and Bluetooth transmission.

The transmitter programs are used for simulation purposes and for the generation of files that can be used by an Agilent E4438C vector signal generator. This generator allows complex baseband signals to be generated and upconverted to radio frequencies up to $6\,$GHz, with a maximum bandwidth of $80\,$MHz. The generated signals can be offered to our analog front-end (see section II).

In our first experiments, a Tektronix TDS 7404 digital oscilloscope is used as ADC. This oscilloscope has a sample rate of $10\,$GS/s and a nominal resolution of $8\,$bit. In a “high-resolution” mode this resolution can be increased; whether this resolution is sufficient for channel selection experiments remains to be seen. We intend to use quadrature sampling at a sample rate of $80\,$MS/s per channel.

For channel selection and demodulation purposes two separate MATLAB/simulink programs are used, one for Bluetooth and one for HiperLAN/2. The programs read the files written by the Tektronix scope and execute the demodulation algorithms.

In both receiver programs, custom data types can be selected. Moreover, the programs enable measurement of the computational cost of the reception algorithms (in terms of and required storage and required number of operations: shift, addition and multiplication). In this way, our test-bed will assist us in partitioning of functionality over implementation components (ASIC, FPGA, DSP, GPP, . . .).

VI. CONCLUSIONS AND FURTHER RESEARCH

In our project we want to use the HiperLAN/2 hardware for Bluetooth demodulation.

For the analog front-end we presented a design of a combined front-end. For the digital channel selection and demodulation function two separate software implementations were designed and implemented.

The aim of this test-bed is to build a multi-standard receiver that enables the generation of knowledge on how to integrate and design a real-time flexible radio-receiver. At this moment and at a functional level, system alternatives are investigated. For instance, one of the most interesting part of the HiperLAN/2 receiver is the FFT. We are researching if this FFT can be used for channel selection and/or for demodulation.

With this test-bed an estimate of the computational complexity (and therefor power consumption) of a system structure and the algorithms used, will be made. This will be done in order to assess the partitioning of system functionality over implementation components. For a future real-time implementation of the digital part of our receiver this knowledge is of paramount importance.

ACKNOWLEDGMENT

This research is supported by the PROGram for Research on Embedded Systems & Software (PROGRESS) of the Dutch organization for Scientific Research NWO, the Dutch Ministry of Economic Affairs and the technology foundation STW.

REFERENCES

[1] V. Arkesteijn, E. Klumperink, and B. Nauta. High-q variable bandwidth passive filters for software defined radio. *Proceedings of the Fourth International Symposium on Wireless Personal Multimedia Communications*, pages 1571–1572, September 2001.

[2] S. Benedetto, E. Biglieri, and V. Castellani. *Digital Transmission Theory*. Prentice Hall, Inc., 1987.

[3] ETSI. Broadband radio access networks (bran); hiperlan type 2; system overview. Technical Report ETSI TR 101 683 V1.1.1 (2000-02), ETSI, February 2000.

[4] ETSI. Broadband radio access networks (bran); hiperlan type 2; physical (phy) layer. Technical Specification ETSI TS 101 475 V1.2.2 (2001-02), ETSI, February 2001.

[5] F. Hoeksema, R. Schiphorst, and C. Slump. Specification for digital channel selection filters in a bluetooth capable hiperlan/2 receiver. 2^{nd} *Karlsruhe Workshop on Software Radios*, pages 41–49, March 2002.

[6] B. Razavi. *RF microelectronics*. Prentice Hall Communications Engineering and Emerging Technologies Series. Prentice Hall, 1998.

[7] R. Schiphorst, F. Hoeksema, and C. Slump. Bluetooth demodulation algorithms and their performance. 2^{nd} *Karlsruhe Workshop on Software Radios*, pages 99–106, March 2002.

[8] B. SIG. Specification of the bluetooth system - core. Technical Specification Version 1.1, Bluetooth SIG, February 2001.