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A software radio–based reconfigurable transponder for space applications‡

Marina Mondin*,† and Letizia Lo Presti
Department of Electrical Engineering
Politecnico di Torino
Torino
Italy

Alessandro Scova
Carlo Gavazzi Space SpA
Milan
Italy

Summary

A novel approach to space communications is represented by the Software Radio (SR) concept, a new technology currently deeply investigated by the scientific community, especially for wireless applications such as mobile communications or wireless network access. The SR approach leads to the definition of a new generation of radio equipment, whose communication functions are almost completely defined by means of software modules. The main outcome of the deployment of this technology is the great flexibility of the radio interface. As a matter of fact the communication standards can be easily reconfigured by simply replacing the corresponding software modules.

This paper describes the SDRsat research project that aims at designing a complete software radio reconfigurable regenerative transponder for space applications. Copyright © 2002 John Wiley & Sons, Ltd.

KEY WORDS
Software Radio
reconfigurability
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1. Introduction

The term Software Radio (SR) refers to an emergent approach in the definition of communication transceivers. An ideal SR transceiver can be viewed as a generic programmable computational device wired to a minimal Radio Frequency (RF) front end. The programmable device performs most of the air-interface functions (covering physical and data-link layers up to the network layer) in the digital domain by means of software-defined components. The advantages of such an architecture with respect

*Correspondence to: Marina Mondin, Department of Electrical Engineering, Politecnico di Torino, Torino, Italy.
†E-mail: mondin@polito.it
‡This work has been conducted in collaboration with CERCOM (Center for Multimedia Radio Communications) software radio research group of Politecnico di Torino, Torino, Italy. www.cercom.polito.it

to the traditional application specific paradigm consist in the possibility of reprogramming or reconfiguring the transceiver to a great extent, allowing different communication standards and services to be run on a common hardware platform [1].

The RF front end is the only analog and the hardwired (non-reconfigurable) part of the communication chain. It poses the most important technical limitation to the multi-standard capabilities of the whole hardware platform, because it dictates the spectral properties (bandwidth and central frequency) of the communication system.

The feasibility of the SR technology relies on the availability of suitable fast (wide-bandwidth) Analog-to-Digital Converters (ADCs) and the availability of microprocessors with enough computational capacity. The state of the art in the field of microelectronics and integrated devices has made most of the aforementioned required components available in the market. Furthermore, the performance of integrated devices with respect to time has a characteristic exponential shape (Moore's law), hence a fast development of the SR-enabling technologies can be foreseen for the next few years.

A lot of work on SR has been performed by the scientific community in the area of mobile communications, where this technology is attractive for managing divergent 2G standards and for softening the transition to 3G standards. Great advantages are also foreseen for the more generic wireless communications field, in which the SR approach can make the development of equipment implementing forthcoming standards faster and easier [2–6].

The main innovation of the SDRsat project presented here is the deployment of the innovative SR paradigm in the field of satellite communications. The project is aimed at designing a satellite transponder exploiting the research outcome of this new technology as a starting point.

The particular communication environment selected is characterized by many available standards, hence many different application-specific conventional communication transponders should be developed if the SR technology were not available. The deployment of the SR concept to design a 'universal' transceiver will allow the on-board equipment providers to move forward in their innovation path: they could more easily develop their own specific products, add new features and communication services and finally achieve a broader market participation, thanks to the great improvement in the capability of quickly developing new products.

2. The SR Transceiver

Traditional transceivers are based on the well-known super-heterodyne scheme (Figure 1a shows the receiving section) in which RF and Intermediate Frequency (IF) stages are totally analog, so that the digital components are present only in the baseband stage, usually built in Application-Specific Integrated Circuits (ASICs).

On the contrary, a pure SR receiver (Figure 1b) has a very reduced analog stage—composed of an antenna, a Low Noise Amplifier (LNA) and a Band Pass Filter (BPF). The Analog-to-Digital (A/D) conversion is performed directly at RF in order to digitally process the signal on a platform that is completely reprogrammable via software.

The software approach is much simpler, cheaper and more flexible than the development of application-specific hardware, but a powerful programmable hardware platform is required by the demanding processing of the communication data stream. Such a platform represents the enabling technology for the implementation of a SR system. With the availability of the suitable programmable hardware, the design and development of the communication system is completely focused on the implementation of the corresponding software functions.

At present, there are technical limitations that make the pure SR transceiver not realizable, mainly because of the high bandwidth needed for the analog stage and because of the ADC.

The most promising solution is the use, in the near future, of an 'IF sampling' scheme (Figure 1c). In this configuration, the ADC samples the overall allocated spectrum after a suitable translation to a lower frequency (IF frequency). After the ADC, the signal is digitally processed employing programmable or reconfigurable devices. A programmable Digital Down Converter (DDC) performs the down conversion, channelization and sample rate adaptation. It is followed by the baseband processing section that performs synchronization demodulation and decoding of the selected channels.

The block diagram shown in Figure 1(c) represents the reference scheme for the project presented in this paper. It is important to note that in order to obtain the processing power needed to perform the real-time execution of the software-implemented radio interfaces, the digital stage may actually be realized by different computing elements—typically Field Programmable Gates Arrays (FPGAs) for high-rate DDC stage and for Digital Signal Processors (DSPs) or

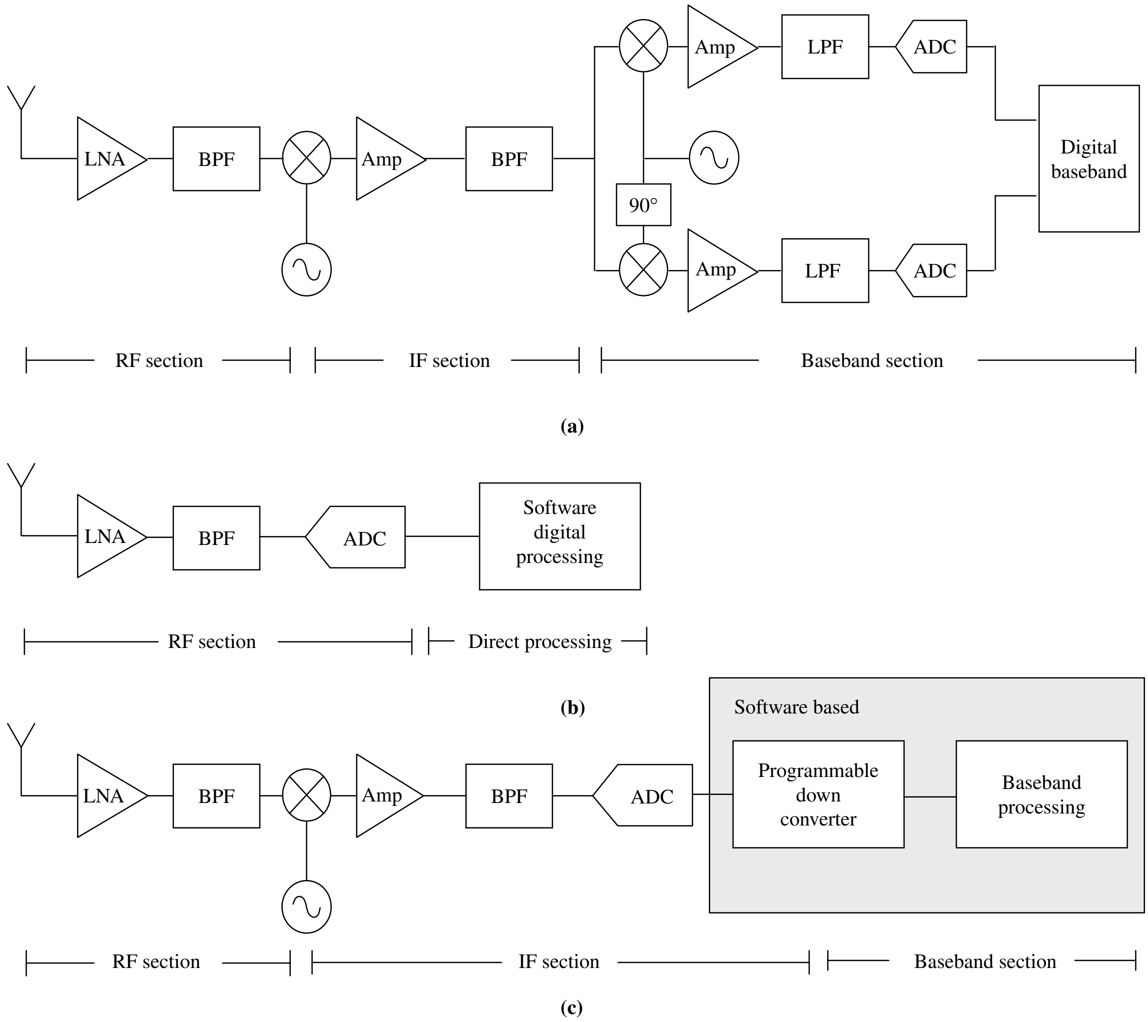

Fig. 1. Block diagram of conventional and software radio receivers.

general-purpose processors for the less demanding baseband processing. Furthermore, to increase the global throughput and to facilitate scalability, a parallel architecture may be exploited (Figure 2).

3. Why a SR Regenerative Transponder?

The most widely used on-board equipment for satellite communication services has been represented for many years by the so-called transparent or bent-pipe transponder, owing to its great simplicity and high reliability. As a matter of fact, a transparent transponder acts as a simple signal repeater, hence it is composed of a small amount of analog components and it is almost independent of the signal format (shaping pulse, modulation and coding).

On the other hand, better communication performances and greater capabilities can be achieved by employing regenerative transponders, which perform on-board data processing. This solution needs a more complex hardware with the consequent trade-off between enhanced capabilities and reliability. Moreover, a regenerative transponder is intrinsically dependent on a particular communication standard. As a consequence, it is impossible to change the transponder application during its operating life and to reuse the transponder design in a different communication environment [7,8].

The proper mix of flexibility, reliability and capabilities may be achieved by means of an SR Regenerative Transponder that is able to overcome the limitations of both kinds of transponders.

Flexibility is given by the possibility to reconfigure the transponder via software in order to process

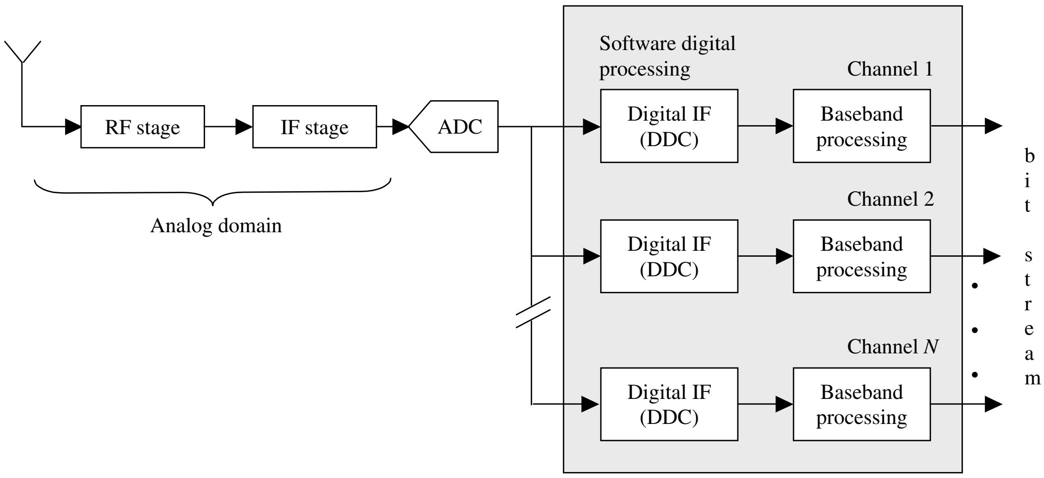

Fig. 2. Architecture of a software radio receiver.

different standards. The software updates may be directly uploaded on-board allowing the extension of the satellites' operational life. Alternatively, the software modules may change from mission to mission. In this way, the advantage lies in a decrease of the costs associated with the design, testing and space qualification of the hardware platform.

Reliability is increased because the SR transceiver can be implemented with a limited number of Commercial Off-The-Shelf (COTS) components, still maintaining the performances and the capabilities of a regenerative transponder.

The comparison between the different transponder technologies is summarized in Table I.

4. Project Activities

The project presented in this paper is performed by a consortium composed of two companies (Carlo Gavazzi Space spa and EuroConcepts srl) and one University (Politecnico di Torino). The purpose of the project is not only the design of the complete system but also the development of a software demonstrator, to be employed as a test bed for the communication modules. All the issues concerning the development of a complete SR system for space applications are taken into consideration: the RF front end, the programmable platform, the radiation hardening of on-board systems, the software architecture, the software modules implementation and so on. The main outcomes of the project will result in a technological demonstrator, while a satellite validation mission is foreseen after the project conclusion.

Table I. Comparison of different technologies.

Transponder	Advantages
Transparent	• Simple ⇒ reliable • Transparent to the signal ⇒ flexible
Regenerative	• Improved communication quality • On-board data processing ⇒ additional functionalities
Software defined	• Reliable (few programmable devices) • Flexible (reconfigurable) • Improved quality (full digital processing) • Additional functionalities (on-board processing)

Figure 3 illustrates the basic platform architecture that has been chosen so far as the reference structure for the reconfigurable transponder (only the receiving section of the transceiver is shown). For the purpose of this project, the *IF sampling* approach has been selected (A/D conversion is performed at IF). This technique allows the achievement of a reasonable trade-off among the reduction of the number of analog components, computational power requirements and the technical feasibility. After an analog front end (antenna, RF and IF sections), the received signal is converted by an ADC and digitally processed by the reconfigurable platform. The platform has been further partitioned into two: a high data-rate processing section DDC, and a lower data-rate processing section (baseband and data processing).

The project activities are segmented into three stages: analysis, design and prototyping.

The analysis stage concerns the selection of a number of communication standards to be implemented on the reconfigurable platform, the study of the satellite mission (environmental constraints, link budget,

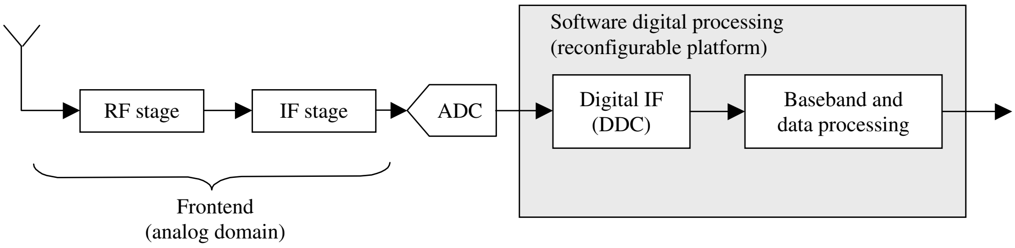

Fig. 3. Architecture of the reconfigurable transponder (receiver section).

etc.) and the evaluation of all the issues related to the integration of the transponder inside the MITA (Minisatellite Italiano a Tecnologia Avanzata) satellite (electrical, mechanical and thermal interfaces, transponder control, electromagnetic compatibility, etc.). MITA is a small satellite developed and validated by Carlo Gavazzi Space for the Italian Space Agency (ASI) and is particularly suited for technological missions, such as the validation of a SR transponder.

The design stage covers all the hardware-related topics: the definition of the RF front end (antenna, LNA, filters, mixers, ADC, etc.), the partitioning of the communication functions with the consequent definition of the hardware architecture (i.e. FPGA, DSP, embedded systems) and its radiation hardening. It also covers the design of the software architecture, that is, the set of programming rules and API (Application Programming Interface) framework required to develop a homogeneous and interoperable library of software modules implementing the communication functions.

The prototyping stage will include the software design and the implementation according to the SR paradigm. The software modules implementing the communication functions are application-specific, while a common (and constant) hardware platform should be used. The prototype stage is aimed at the development of the software functions required by the selected applications. High data-rate functions, such as digital down conversion, are implemented in FPGA, while all the remaining baseband processing can be implemented by means of a proper high-level language. For the implementation of the baseband functions of the transponder, the C++ programming language has been selected, chiefly because it is an object-oriented language (well suited to the modular architecture of a communication system) and at the same time it makes it possible to obtain a fast and highly optimized executable code.

As far as the SR blocks are concerned, the library STAR, developed by EuroConcepts srl will be employed, which contains many of the most employed functional blocks of a SR communication system, such as modulation/demodulation, coding/decoding, synchronization, filtering and so on. STAR also provides a programming framework, whose purpose is to enable the development of new communication blocks, built up on a common basis and providing a standard interface.

The prototype stage is not only aimed at the software development but also at providing a software technological demonstrator at the end of the project. The demonstrator is intended to behave as a real-time test bed for the communication chain and future new software modules. The software demonstrator will be developed on commercial embedded systems linked together or, more likely, on high-performance workstations.

It is important to notice that the project activities follow some of the main guidelines provided by the major international space agencies in the field of next-generation technologies for space applications [9–13]. These guidelines aim at leading the research to remove the great disparity between space and commercial technologies, with particular attention to the exploitation of the commercial Information Technology (IT) outcome for space applications. The deployment of reconfigurable payloads, COTS components, commercial software tools and operating systems and high-performance commercial hardware are some of the issues that can be considered attractive for the purpose of increasing the technological level of the space missions.

5. Conclusion

The main objective of the SDRsat project described in this paper is the validation of the SR technology for reconfigurable space applications, with the purpose of exploiting this innovative paradigm to increase the technological level of space communication payloads, according to the major trends in the research for space applications.

Exploiting a 'generic' computational platform for a specific application such as implementing a communication system has many advantages. As a matter of fact, a reconfigurable platform employing commercially available components allows the quick design and development of new equipment, the reuse of the same hardware for different products and greater on-board flexibility by means of remote reconfiguration. All these features lead to cost reduction and a great improvement in time-to-market.

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Authors' Biographies

Alessandro Scova received the Laurea in Electrical Engineering (equivalent to M.S. degree) with concentration in Communication Engineering from Politecnico di Torino, Turin, Italy, in 2000. During the 2000–2001 time period he worked as a researcher under grant with the SAS (Signal Analysis and Simulation) group of the Department of Electrical Engineering of the Politecnico di Torino. His research focus in this period was in the area of SAR (Synthetic Aperture Radar) signal processing and wireless communication systems. He also taught a course on digital transmission theory during this period. At present he is working for Carlo Gavazzi Space, an Italian company involved in the aerospace market, in cooperation with Euroconcepts. His current R&D activity is focused in areas of signal processing (theory and implementation), digital communications and software radio for space applications.

Marina Mondin was born in Turin, Italy. She received the Laurea in Ingegneria Elettronica (summa cum laude) in 1986, and a Ph.D. degree in Electrical Engineering in 1990, both from Politecnico di Torino, Turin, Italy.

In 1987, she was recipient of the 'De Castro' scholarship, and she spent the year 1987 to 1988 as visiting scholar in the Department of Electrical Engineering at the University of California, Los Angeles.

Since 1990 she is with the Dipartimento di Elettronica, Politecnico di Torino, where she is currently associate Professor. She is a member of the IEEE Communications and Information Theory Societies. Her current interests are in the area of turbo coding, trellis-coded modulation, simulation of communication systems, application of wavelets to digital communications and software radio.

From 1999 to 2000 she acted in the capacity of senior scientist for TechnoConcepts, Inc. where she directed the software development efforts. In 2000 she co-founded EuroConcepts s.r.l., an R&D company specializing in the design of advanced communication links and software radio.

Letizia Lo Presti was born in Palermo (Italy) in 1947. She received the degree in Electrical Engineering with specialization in signal processing and communications from Politecnico di Torino in 1971. In 1972 she joined, as a researcher, the Institute of Electronics and Telecommunications (now Department of Electronics) of Politecnico di Torino, where, at present, she is associate professor of signal theory.

During her career, she has taught many courses at both the graduate and undergraduate level including Signal Theory I (a basic course in Signal Analysis); Signal Theory II (an advanced course in Time-Frequency Distributions and Wavelet) and Digital Signal Processing.

In the period between July and December 1996 she was visiting researcher at the Electrical and Computer Engineering Department of the California State University, Los Angeles. Her research activities cover the field of digital signal processing (e.g. digital filters and wavelet transform for geophysical signals), array processing for adaptive antennas, data compression, and simulation of telecommunication systems.

She has over 25 years experience in the field of simulation of communication systems. Among her multitude of accomplishments, we may list the following:

(i) Principle investigator on numerous national and European funded research contracts; (ii) One of the creators of TOPSIM-IV simulation package. This time-driven simulation package is among the very few solid simulation packages recognized internationally with proven performance over a decade of simulation and verification against build systems; (iii) Author of two signal processing textbooks on deterministic and random signal processing; (iv) Lead project coordinator for performance evaluation of lossless compression schemes in a satellite environment under Inmarsat contract (1994–1995 period); (v) Lead project coordinator for development of the RICE decompressor, under ESOC contract No. 12488/97/D/DK 'Implementation of a CCSDS decompression library'; (vi) Author of over 100 journal papers and conference publications; (vii) director of the Signal Analysis and Simulation (SAS) group of the Politecnico di Torino; (viii) Thesis advisor of numerous M.S. and Ph.D. students, many of whom are under contract with the SAS group; and (ix) Among the main authors and CO-PI of the Helinet project, a research consortium of several universities whose aim is to conduct research on stratospheric platforms for communications and surveillance missions.

