

Software Defined Radio Platform and Application Analysis

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Abstract: This research first introduces the basic concepts and development history of software-defined radio. Secondly, it specifically describes several structures of software-defined radio technology and makes detailed comparisons. Meanwhile, it expounds several key technologies of software-defined radio technology. Thirdly, it discusses several commonly used hardware platforms of software-defined radio and the matching software platforms, and analyzes the advantages and disadvantages of each platform in detail. Finally, the application scenarios of software-defined radio technology were analyzed.

Keywords: Software Defined Radio; Structure; Platform; Application; Key technologies.

1. Overview of Software Defined Radio

Software-defined radio is a multi-band radio that features a wideband antenna, RF conversion, ADC/DAC, and can support multiple air interfaces and protocols. Ideally, all aspects, including physical air interfaces, can be defined through software. Software-defined radio is a new type of wireless architecture, which enables wireless networks and user terminals to have reconfigurable capabilities through the combination of hardware and software [1]. Software-defined radio provides an effective and rather economical solution for establishing multi-mode, multi-band, and multi-functional wireless devices, and its functionality can be enhanced through software upgrades. It enables the entire system (including user terminals and networks) to reconfigure device characteristics through dynamic software programming. The same hardware can accomplish different functions through software definition.

The core idea of software-defined radio is to adopt an open, standardized and universal hardware platform. Second, the broadband A/D and D/A conversions should be as close as possible to the antenna [2]. The third is to implement as many radio functions as possible with software; The fourth is to achieve the setting and upgrading of system functions through software. The development of software-defined radio has gone through three stages, namely digital hardware radio, software-controlled radio and software-defined radio. In the digital hardware radio stage, there is no software involved, and the system cannot be modified in any way. System operations are accomplished by switches, dials and buttons. In the software-controlled radio stage, the control function is implemented in the software. However, without changing the hardware, these wireless communication devices cannot change characteristic parameters such as frequency bands or modulation methods. In the software-defined radio stage, software is involved in processing and control. The system can use software to control modulation, wide/narrow band, security, waveform generation and detection, but is usually constrained by frequency. The concept of soft radio originated

in the 1970s when the US military developed multi-mode radio systems in the VLF band [3]. In 1978, the United States Air Force developed the Integrated Avionics (ICNIA) system for Communication, Navigation and identification. The highly integrated avionics system, the CNI subsystem, on the fourth-generation fighter aircraft developed by the United States. The CNI system could support 22 different signal waveforms for communication, navigation and identification, and can provide radio communication from HF to L band. The "speakeasy" (Easy Communication) software radio station developed by the US military and Hazeltine Company has completed the feasibility study and applicability verification of constructing a multi-band and multi-mode radio (MBMMR) system based on the concept of software radio. After the SPEAKeasy project, the Programmable Modular Communication System (PMCS) was developed and subsequently became the foundation of the JTRS radio station. As time goes by, the application of software-defined radio technology has gradually shifted from military communication to civilian mobile communication. In the future, software-defined radio will develop in the direction of intelligence and it will become the core technology in the field of radio communication in the 21st century.

2. Software-Defined Radio Architecture

Software defined radio architecture is the realization of software defined radio read the specific design structure, including hardware, software and interfaces Agreements and other parts [4]. Software defined radio architecture is software none the core of wire technology. The software defined radio hardware architecture is divided into four types according to the connection mode of each functional module in the system: pipeline-type structure, bus-type structure, switching-type structure and network-based structure. The assembly line structure is shown in Figure 1. The bus structure is shown in Figure 2. The switched structure is shown in Figure 3 and the network structure is shown in Figure 4.

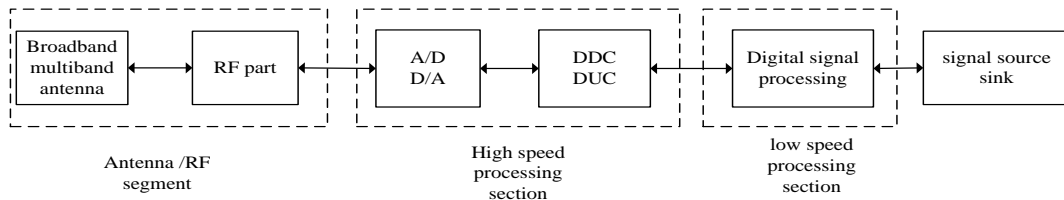


Figure 1. Pipelay structure

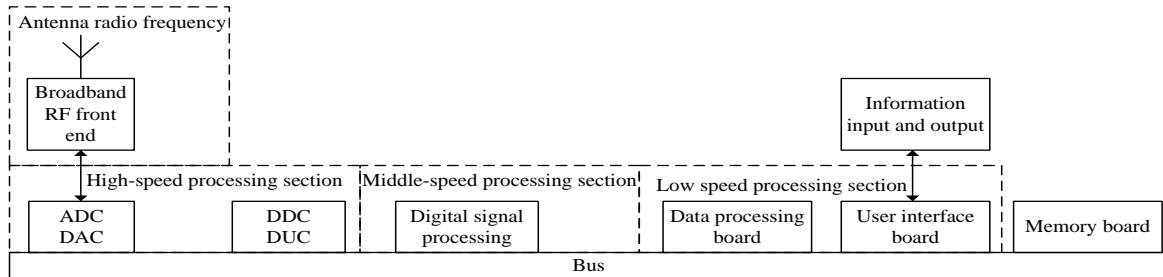


Figure 2. Bus structure

Pipelay structure has the advantages of short delay, simple hardware, good real-time performance and high processing speed. However, there are also some modules with tight coupling and low independence. It is not open and can not meet the shortcomings of complex soft no system. The bus structure has the advantages of good openness, simple structure, high modularity and flexibility, but it has the bottleneck of system function expansion. The switched

architecture has the advantages of good openness, high throughput, broadcast or multicast, but it has long time, complex hardware and high cost. The network structure has the advantages of good openness, high throughput, high efficiency and good generality, but it has the same advantages as the switched structure, such as long time, complex hardware and high cost. The specific comparison of software-defined radio hardware architectures is shown in the table 1.

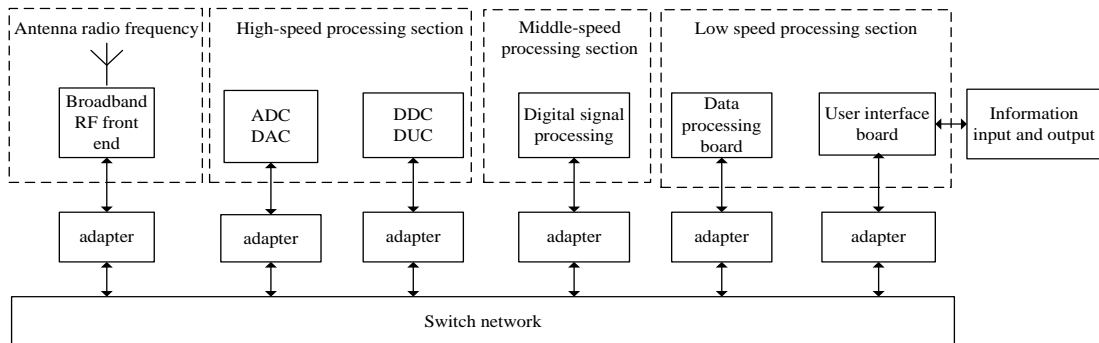


Figure 3. switched architecture

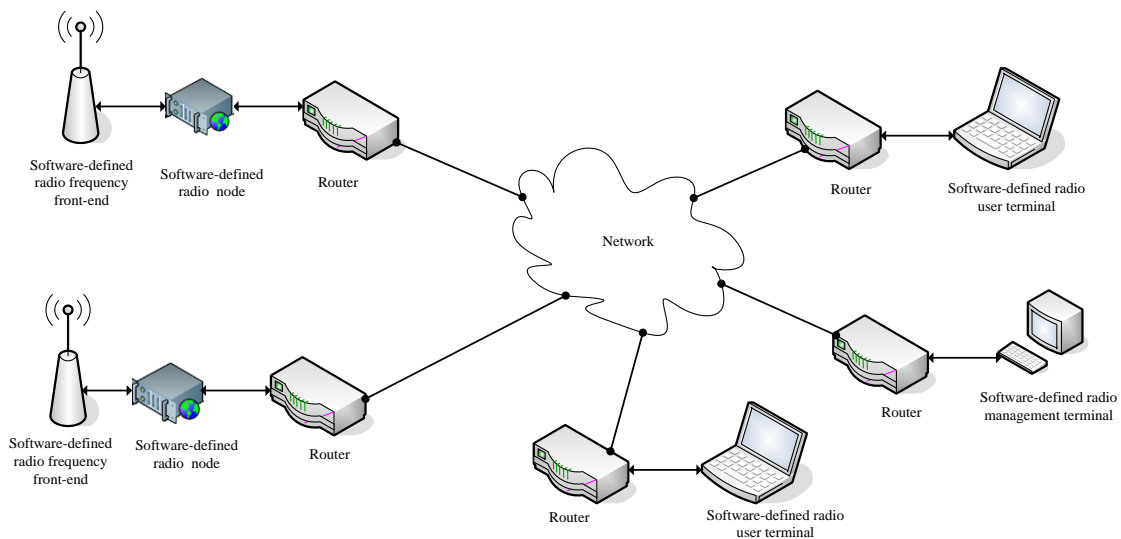


Figure 4. network architecture

Table 1. Comparison of several structures

Type	efficiency	delay	bandwidth	complexity	flexibility	universality
Pipelay structure	The highest	shortest	narrow	simple	poor	poor
Bus structure	low	shorter	wide	simple	good	good
Switched structure	higher	long	wide	easy	good	good
Network structure	higher	long	wide	easy	good	good

3. Software-Defined Radio Core Technology

Software Defined Radio (SDR for short) is a kind of wireless communication technology based on software definition. Its core technologies cover multiple aspects, including radio frequency, front end, baseband, software and security, etc. These technologies together constitute the complete framework of software-defined radio systems, enabling them to flexibly adapt to various communication requirements and be compatible with different standards.

Frequency technology is one of the cores of software-defined radio, and its main task is to achieve the reception and transmission of radio frequency signals. In software-defined radio, the RF front end typically employs wideband or wideband multi-band antennas to cover a frequency band range from 2MHz to 2GHz or even wider. In addition, the RF front end also includes wideband A/D converters and D/A converters, which are used to digitize analog signals and restore digital signals to analog signals. To enhance performance, the RF front end is usually placed close to the antenna to reduce signal interference and improve signal processing efficiency. Software-defined radio systems need to support a wide range of frequency bands, so broadband/multi-band antenna technology is of crucial importance. This kind of antenna can receive and send signals of different frequency bands, thereby meeting the requirements of multi-standard communication. For example, through combined multi-beam antennas or intelligent constructed antennas, efficient processing of signals in different frequency bands can be achieved.

Digital signal processing is one of the core technologies of software-defined radio. It is responsible for demodulation, filtering, encoding and decoding of the received signals. DSP technology accomplishes complex signal processing tasks through high-speed processors such as FPGA, DSP or general-purpose CPU/GPU [4]. The application of DSP technology enables software-defined radio to dynamically adjust channel bandwidth, modulation methods and encryption algorithms, thereby adapting to different communication environments. High-speed A/D and D/A converters are important components of software-defined radio. They are responsible for converting radio frequency signals from the analog domain to the digital domain and restoring digital signals to analog signals. The performance of these converters directly affects the sampling rate, quantization bit number and dynamic range of the system. To meet the requirements of high-speed data processing, modern software-defined radio systems usually adopt parallel A/D and D/A conversion schemes. One notable feature of software-defined radio is its openness and modular design. By loading different software modules, various communication functions can be achieved, such as modulation and demodulation, channel coding and encryption, etc. This modular design not only enhances the flexibility of the system, but also reduces the costs of upgrading and maintenance. In

wireless communication, security is a key issue. Software-defined radio protects communication content through encryption algorithms and security protocols to prevent information leakage and illegal access. In addition, security technology also includes the improvement of anti-interference and anti-destruction capabilities to ensure the reliability and confidentiality of communication. The hardware platform of software-defined radio usually adopts A bus structure, including antennas, radio frequency modules, wideband A/D and D/A converters, digital signal processors, etc. This structure supports the connection of modular and standardized hardware units, enabling the system to be expanded and upgraded as needed. Smart antenna technology is an important component of modern software-defined radio. It can automatically track and adjust the beam direction, thereby improving signal quality and anti-interference capability. This technology is widely applied in military communication, mobile communication and radar systems. Software-defined radio systems typically operate on real-time operating systems and adopt a distributed processing architecture to enhance computing efficiency. This architecture supports multi-task parallel processing and can respond quickly to real-time communication requirements. With the advancement of technology, software-defined radio is evolving towards higher integration, wider frequency band coverage and greater flexibility. For instance, future software-defined radio systems might incorporate artificial intelligence algorithms to further enhance signal processing capabilities and adaptive performance. The core technologies of software-defined radio cover multiple aspects such as radio frequency, wideband antennas, digital signal processing, analog-to-digital converters, modular design, security technology and smart antennas. These technologies jointly constitute a flexible, efficient and scalable wireless communication platform, enabling it to demonstrate great application potential in fields such as military communication, mobile communication, electronic warfare and information appliances.

4. Software-Defined Radio Platform

4.1. Software-Defined Radio Software Platform

The most popular software platforms for software Radio are GNU Radio, LabVIEW and Simulink. GNU Radio is an open source software Q Defined Radio (SDR) platform. It has a worldwide community of developers and users who contribute a solid base of code and provide many practical applications of software and hardware. It provides a complete development environment to create your own radio, dealing with all the hardware interfaces, multi-threaded Q, portability issues for you. GNU Radio provides all the libraries needed for general purpose software radios, including various modulation modes (GMSK, PSK, QAM, OFDM, etc.), error correction codes (R-S codes, Vitbi codes, Turbo codes), signal processing modules (optimal filters, FFTS, equalizers, timing

recovery), and scheduling. It is a flexible system that allows users to develop applications in C++ or Python. The code is completely open, and users can configure it according to their

own system requirements. Connect the required modules in the GRC (GNU Radio Companion) to build a flowgraph.

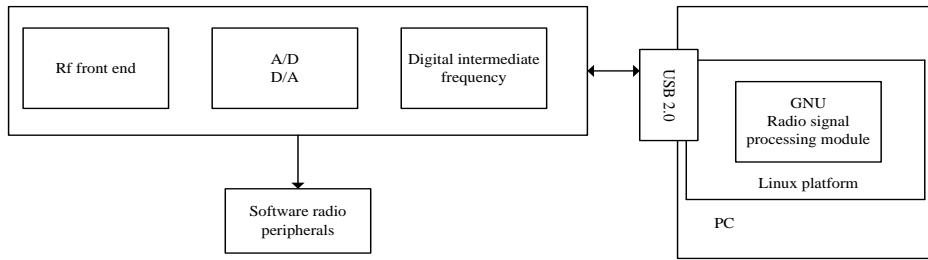


Figure 5. GNU structure

LabVIEW is a visual programming platform, which contains rich tool resources and is a software development environment suitable for a variety of platforms [5]. LabVIEW replaces traditional programming languages with program block diagrams and simplifies programming, which is the biggest feature of LabVIEW that is different from C++, Java and other programming languages. LabVIEW software has strong flexibility and convenience, which can separate the design of the software's human-computer interaction interface from the program block diagram. There are a few packaged function libraries in LabVIEW software, which can be called directly in the process of designing the system. At the same time, it encapsulates some standard library functions, such as TCP/IP, FFT, etc., and supports VXI, RS-485 and other data acquisition cards and protocols, which can be applied to many operating systems. For example, in Windows and Linux, you can generate executable files that run independently. In addition, LabVIEW can also call MATLAB and C languages through the toolkit to improve usability. LabVIEW is a powerful and easy to use software. The compatibility and openness of the system designed by the LabVIEW program can be well reflected. This experiment will also be designed based on the LabVIEW software platform. The VI file is the core of the entire LabVIEW software, which mainly includes the front panel and the back panel (program block diagram panel). The main purpose of the front panel is to achieve human-computer interaction, command operation through data input. Commonly used controls have input and output boxes, switches, graphics, etc., its concise, intuitive and easy to understand, the back board is mainly the creation and planning of the program, using the form of graphical language to write programs. When the program is running, the data is input to the control end of the front panel, and the program of the back panel will process it at the same time, and then present it through the display control of the front panel after the processing is completed. In order to process the data

received by the USRP, it is necessary to install the NI USRP hardware driver in the LabVIEW software development environment, which can control the USRP hardware devices in real time, such as adjusting hardware parameters and capturing data. In addition, it is necessary to install the signal modulation and demodulation kit, which contains the basic data modulation and demodulation function library, which is convenient for users to call directly.

Simulink is a kind of dynamic system modeling, simulation and comprehensive analysis of the integrated software package, a drawing software in Matlab environment, is an important part of Matlab. it has a lot of can supplement will define the module library, graphical generator and analyzer to verify the simulation results, and analyze the performance and design error, model role parsing and analysis tools to ensure the identity of the model, characteristics of clear errors in the model, so as to be broader range of applications. At the same time, simulink simulation modeling diagram does not need to edit the code like other software, but only need to click the mouse drag icon, you can build a variety of complex systems, making the system simulation difficulty is greatly reduced. The Matlab/Simulink support package is available from Math works in the united states for free. It enables the hardware development board to be fully supported by Simulink, not only allowing system modeling and simulation, but also allowing automatic code generation and download to the hardware board. A simple configuration on the software interface is all it takes. Similar software domestic manufacturers developed e-LabRadio software platform, it also adopts the graphic design concept, provides a wealth of communication algorithm particles, including source coding and decoding, channel coding and decoding, digital modulation and demodulation, high-pass/low-pass and other efficient filtering, digital codestream transformation, frequency identification, stereo synthesis and so on [6].

Table 2. Comparison of several software radio platforms

software	Development language	platform	peculiarity
GNU Radio	RadioPython and C++	C++Linux and Windows	Free open source radio software development framework, modular design, supports all USRP, provides rich blocks to handle a variety of signal operations, suitable for complex signal processing
LabVIEW	G Programming language	Windows and MacOS	The intuitive graphical programming tool can be used to realize complex system configuration, DSP design of multiple rates in FPGA, etc., suitable for data acquisition and instrument control
MATLAB	MATLAB language	Windows, MacOS and Linux	A commercial software with powerful algorithm development and simulation capabilities that can be used in conjunction with USRP for wireless research and algorithm validation like SISO and MIMO
Simulink	MATLAB language	Windows, MacOS and Linux	A commercial software with powerful algorithm development and simulation capabilities, used in combination with MATLAB to provide a graphical simulation environment

4.2. Software-Defined Radio Hardware Platform

Some popular SDR modules include HackRF One, KiwiSDR, RealTek RTLE-SDR, Ettus Research Universal Software Radio Peripheral (USRP) N210, USRPN200, Analog Devices Active Learning Module (ADALM)-PLUTO and National Instruments (NI) SDR module, Such as USRP 2901, USRP 294x, USRP 295x. These SDRs are compatible with various programming platforms such as GNURadio, Laboratory Virtual Instrument Engineering Workbench (LabVIEW), Matrix Lab (MATLAB) [7].

The HackRFOneSDR is a half-duplex RF transceiver that supports 1MHz to 6GHz and it is compatible with GNU Radio; KiwiSDR supports shortwave, long-wave, and AM broadcast bands, as well as different public stations and amateur wireless transmissions in the frequency range from

10 kHz to 30 MHz. The RTL-SDR supports frequencies between 500 kHz and 1.7 GHz and is suitable for air traffic control, general radio scanning, and public safety radio applications. Supporting frequencies up to 6GHz, Ettus Research USRP N210 is a high-performance, fully integrated, and inexpensive single board SDR. The ADALMPLUTOSDR is another half-duplex RF transceiver that is compatible with MATLAB and supports 325MHz to 3.8GHz. NI USRPs such as NI 294X, NI 295X, and NI 2901 are another class of RF transceivers compatible with LabVIEW software. These USRPs support wideband operation because they have sampling and synthesis bandwidth from the 30-120MHz range, which is 1 million times larger than PC sound cards []. For this work, NIUSRP-2901 was used, which supports carrier frequencies between 70 MHz and 6 GHz. In the existing literature, various experimental prototypes for different wireless applications have been established using the SDR module described above.

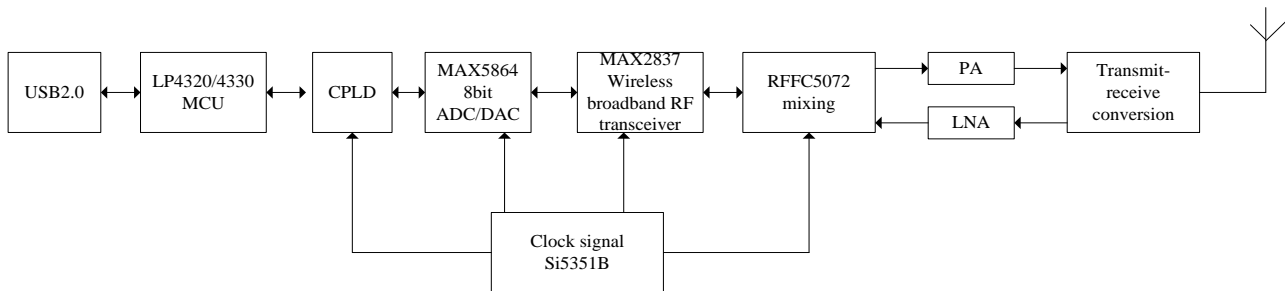


Figure 6. HackRF hardware architecture

(Muslimin, 2016) demonstrated a 40MHz universal transceiver for digital modulation systems using two USRP N210 devices and GNUradio [8]. (Chamran, 2019) developed a distributed test platform for 5G scenarios using a USRP N200 programmed by GNUradiosoftware with Raspberry Pi3B+ as the decision engine [9]. Multi-hop transmission via four intermediate USRP modules, using User Datagram Protocol (UDP) packets to send video streams to their destinations. End-to-end latency of cognitive networks operating at 850 MHz licensed TV band frequencies is studied under different processing scenarios. SDR supports the development of simple wireless digital links to advanced 5G network prototypes.

Some of the SDR modules used in cognitive link applications are described below. UHF TV bandwidth signals of 470-790 MHz were captured by MATLAB using ADALM PLUTO SDR for broadband spectrum sensing in cognitive radio [10]. (Molina-Tenorio, 2021) investigates a robust multi-band spectrum detection method for cognitive radio using four USRP modules and a mobile phone [11]. The HackRF One SDR, RTL SDR 0005 and RTL SDR 0002 are programmed to operate at 835 MHz, 846.2 MHz and 848.6 MHz respectively. The Lime SDR mini is programmed as an OFDM transmitter at 847.8 MHz. (El Bahi, 2019) using two NI USRP 2930 devices, demonstrated real-time OFDM based spectrum sensing at 433.92 MHz carrier frequency using a semi-blind detector, by considering Rayleigh fading and flat fading environments [12]. Namely based on singular value decomposition (SVD) (El Bahi, 2016) and energy detector [13]. (Perumal, 2022) developed a test bed using USRP 2920 for demonstrating dynamic spectrum sensing using a wavelet approach, on a carrier frequency of 2GHz [14].

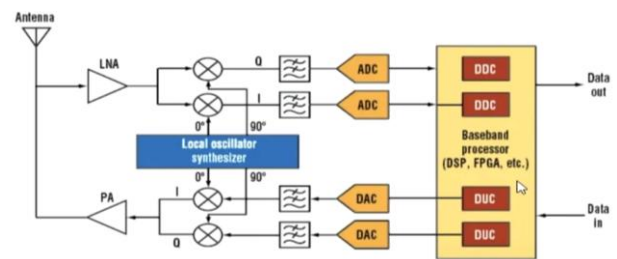


Figure 7. USRP structure

The USRPE320 is a high-performance, stand-alone SDR device that covers 3MHz to 6GHz and provides 200MHz of instantaneous bandwidth per channel. The USRPE320 delivers superior performance to embedded SDRs by providing four times more FPGA resources than the USRPE31x device. It uses highly integrated RFIC and FPGA to simplify costs, wide frequency coverage, and fast PC connection via USB interface. The USRP X410 is the fourth generation of software-defined radios (SDRS) in the USRP SDR family and is the latest generation of products with high performance and multi-channel features. The USRP X410 has a center frequency tuning range of 1MHz to 7.2GHz. The USRP B210 is a fully integrated single PCB board general purpose software radio software platform that provides 2 Tx/Rx channels, uses the AD9631 as the RFIC, and has a frequency range of 70MHz to 6GHz and a bandwidth of up to 56MHz. It is equipped with USB3.0 interface. It provides a fully integrated, single-board, universal software radio Peripherals (USRP) platform that provides continuous frequency coverage in the 70MHz-6GHz range. Designed for low cost experiments, it combines the AD9361RFIC direct conversion transceiver to provide up to 56MHz real-time bandwidth; An open and reprogrammable Spartan6 FPGA; Fast USB3.0 as bus power supply. Full support for USRP

Hardware Driver (UHD) software allows you to start developing with GNURadio immediately, create your own prototype GSM base station with OpenBTS, and seamlessly transition from USRPB210 to the higher-performing, industry-grade USRP platform. An accessory kit is available for users of green PCB devices (revision6 or later) to assemble a protective steel case.

The USRPB210 was tested in a wide range of applications, including: FM and TV broadcasting, cellular telephony, GPS, WiFi, ISM, and more. Users can begin prototyping immediately in GNURadio and participate in the open source SDR community. Comprehensive support for UHD software allows for seamless code reuse of existing designs, compatibility with open source applications such as HSDR and OpenBTS, and upgrades to industry-grade USRP systems

to meet application needs. The integrated RF on the USRPB210 is based on the AD9361 design, which is a single-chip direct conversion transceiver capable of transmitting real-time RF bandwidth up to 56MHz. The B210 uses two signal chains from the AD9361 to provide consistent MIMO capability. The onboard signal processing and control of the AD9361 is performed by a Spartan6XC6SLX150 FPGA that is connected to the host PC using SuperSpeed USB 3.0. The USRPB210's real-time throughput is quadratically modulated at 61.44MS/s, giving the host PC an instantaneous RF bandwidth of 56MHz for additional processing using GNU Radio or applications using the UHDAPI. These products are based on the Universal Software Defined Radio Peripheral (USRP) platform and can be used to design, prototype, and deploy radio communication systems.

Table 3. Comparison of several kinds of hardware platform

Hardware platform Parameters	HackRF	bladeRF		USRP	
		x40	x115	B200	B210
Frequency	30 MHz-6GHz	300MHz-3.8GHz		50MHz-6GHz	
Bandwidth	20MHz	28MHz		61.44MHz	
duplexing	Half	Full		Full	2x2MIMO
AD sampling bits	8 bit	12 bit		12 bit	
AD sampling rate	20 Msps	40 Msps		61.44 Msps	
Interface (rate)	USB2 HS	USB3(5 gigabit)		USB3	
FPGA logic device	A CPLD on the board no FPGA	40k	115k	75k	150k
Microcontroller	LPC43xx	Cypress FX3		Cypress FX3	
Open source	Everything	HDL+Code		Host Code	
Cost	\$300	\$420	\$650	\$675	\$1100

5. Software-Defined Radio Application

Software-defined radio technology is widely applied in the third and fourth generation mobile communication systems (such as 3G and 4G), achieving compatibility and upgrading of multiple communication protocols through flexible software-defined functions, thereby enhancing the universality and flexibility of the system [15]. For example, in the TD-SCDMA system, software-controlled radio combined with smart antennas and joint detection technology has significantly improved the anti-interference performance. Software-defined radio technology also has important applications in the field of satellite communication. It can support functions such as broadband digital module technology, real-time modulation and demodulation, and adapt to different frequency bands and channel conditions. Software-defined radio technology, due to its flexibility and configurability, is used to build Internet of Things devices and smart home systems. For example, through software-defined radio equipment, users can easily change system parameters to adapt to different environmental requirements. Software-defined radio originated in the field of military communication initially to address the interconnection and interoperability issues among different radio stations. Its anti-interference ability and flexibility make it an important component of modern tactical communication systems. Software-defined radio platforms can be used for spectrum monitoring. Through FFT processing, the spectrum situation is displayed in real time, which helps to analyze the channel occupancy in the wireless channel. Software-radio technology is also widely applied in shortwave communication and can achieve multi-mode and multi-

channel communication through wideband antennas and multi-band RF converters. Cognitive radio technology based on software-defined radio can sense the surrounding electromagnetic environment and dynamically adjust communication parameters (such as frequency, power, modulation mode, etc.) to improve spectrum utilization and communication reliability. Software radio platforms such as YunSDR are used in research and teaching experiments of wireless communication systems, supporting wideband signal processing and embedded architectures.

In conclusion, software-defined radio technology, with its flexibility, scalability and efficiency, which has demonstrated extensive application potential in multiple fields such as mobile communication, satellite communication, Internet of Things and military communication.

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