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A Review On Software Defined Radio (SDR) In Communication

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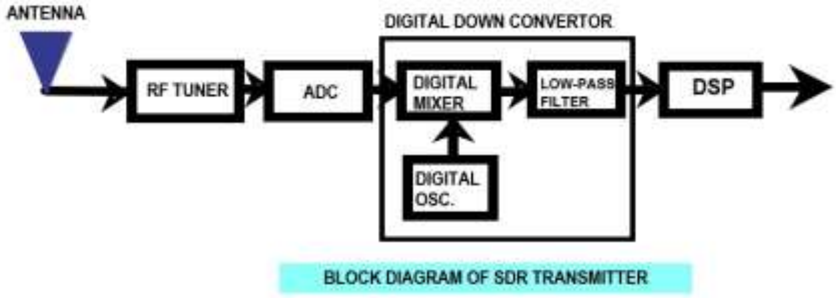
Abstract: This paper reviews the software-defined radio (SDR) technology in the Communication platform where this technology is widely used to modify, and reconfigure the system and new adaptions in the current technology. SDR is a type of radio communication that uses software to perform previously executed parts on traditional hardware. SDR has applications from telecommunications to the military and has evolved over the last three decades. SDR systems are useful for digital and analog wireless communications, wideband networks and emergency radio. A radio transceiver, software, and a computer are the main components of SDR systems. SDR technology will continue to evolve and dominate the technological market as the industry progresses toward the latest versions of SDR, such as cognitive and intelligent radios.

***Index Terms* - Communication system, Modulation, Radio communication.**

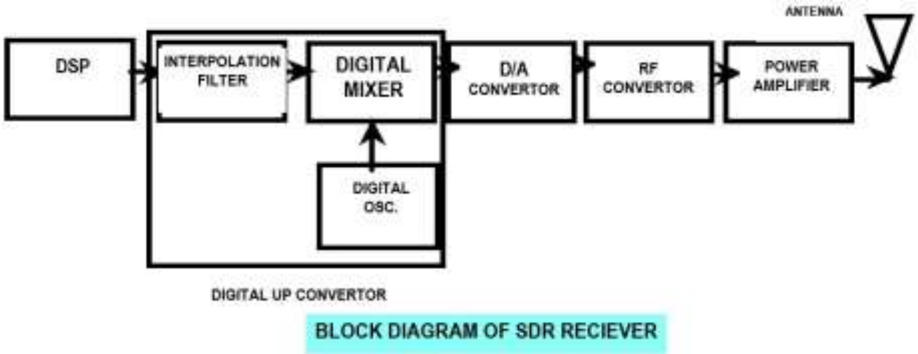
I. Introduction

Software-defined radio (SDR) is a radio technology in which important communication system functions are performed in software utilizing digital signal processing methods. This enables numerous protocols, rapid updates, and entire radio feature reconfigurations. In SDR, the formerly executed elements on conventional hardware are now executed in software on a desktop computer or embedded platform [1]. The traditional communication system through a radio requires a large hardware platform including filters, modulators, converters etc. which makes it inefficient for extended applications. To overcome this issue the use of software-designed components for implementing the radio communication system is applied [2]. A significant amount of the processing of signals, including selecting a channel, tuning, modulation, and decoding in SDR, is done in the domain of digital signals using software [3] [4].

Joseph Mitola III developed the term "Software-Defined Radio" (SDR) in 1992 to describe a technique that employs software to regulate radio hardware. Mitola, a US Naval Research Laboratory researcher, witnessed the potential of software in controlling radio hardware and therefore developed a software radio framework. By this evolution, SDR technology has emerged as a critical field of study in the field of communications [5]. SDR has been in the technology market for the last 3 decades and has evolved as a dominant focus of the industry. Ranging from telecommunication to the military, SDR has evolved and has scope for a more advanced future [6]. From normal radios to software-defined radios the industry is moving towards advanced cognitive and intelligent radios which will team up with AI solutions to create a more advanced setup for future generations [7]. In this way, the designed system is more adaptable to changing technology and is reconfigurable which will further ease the process of designing the system by running more applicable software on the same hardware.



(a.)



(b.)

Figure 1 Block Diagram of SDR (a) Transmitter (b) Receiver

The information is digitally processed by the transmitter and converted into a unique electromagnetic sinusoidal waveform, which is defined by its physical characteristics, such as signal amplitude, carrier frequency, and phase [8] [9]. On the other end of the communication link, the receiver's task is to correctly identify the physical characteristics of the intercepted modulated waveform that is transmitted across a potentially noisy and distortion-filled channel, and ultimately convert the intercepted signal into the correct binary representation. [10]. As an outcome, the ultimate objective of SDR is to relocate the analog-to-digital converter (ADC) or digital-to-analog converter (DAC) as close to the antenna as is practical so that all of the signal handling may be done dynamically through software [11].

SDR systems can be used for a variety of applications, including both digital and analog wireless communications, wideband networks, spread spectrum, navigation waveforms, emergency radio, and security for the public [12]. Depending on the waveform, design, and implementation, SDR systems can provide a wide range of communication services. SDR technology lowers production as well as evaluation costs, enabling faster transitions to newer digital signal-processing techniques and service-oriented applications [6].

This review explores software-defined radio (SDR), as an innovative technology in modern communication. It describes its definition, history, and use in a variety of disciplines. The evaluation concentrates on its hardware and software components, benefits, and applications in military, commercial, and emerging industries. Additionally, it embraces issues like security, interference, and regulatory concerns. In addition, the study examines current advances and future trends in SDR, emphasizing extending research and developments. According to the review, SDR is an adaptable and reliable tool for modern communication that can make communication faster and more secure in the upcoming generations.

II. Principles And Components Of Software-Defined Radio

Radio communication is the transfer and receiving of radiation from the electromagnetic spectrum utilizing radio waves with frequencies ranging from 30 KHz to 300 GHz [13]. SDR is wireless equipment that processes radio waves using programming rather than typical analog hardware components such as mixers, filters, amplifiers, modulators, and detectors [14]. SDR technology can broadcast and receive signals at many frequencies, enabling wireless communication systems such as FM radio, beyond 5G, LTE, and WLAN to be implemented [10] [15]. The radio's operations are specified in the digital domain, and the system may be reconfigured by modifying the functioning of the software. The dynamic properties of the system, as well as additional communication system improvements, can be adapted for the software-defined radio architecture. This technology applies to any updated device that communicates by radio frequency (RF), including cellular base stations, defence communications systems, and emergency radios [16].

The research on SDR-based wireless systems by Molla et.al, and Duarte et.al, investigates the usage of software-defined radio (SDR) technologies for RF transceivers, with an emphasis on the general-purpose processor (GPP)-based systems that comply with the minimal criteria of wireless standards [17]. It focuses on the design as well as the efficiency of SDR platforms in terms of frequency range, bandwidth, symbol rate, bitrate, and latency support. In addition, the study includes a list of GPP-based SDR platforms for existing wireless technology implementations, backed up by theoretical conclusions and tests [18].

The article by Geng et.al studies the existing and different platforms of SDR implementation, focusing on bandwidth support and high-frequency range. The article provides a comprehensive list of GPP-based SDR systems that meet wireless communication requirements. The study focuses on the core weaknesses in conventional approaches, such as limitations in programmability and flexibility. It also discusses various wireless transceivers and their implementation design [19].

Overview of the key components of the SDR system

A radio transceiver, software, and a computer comprise a software-defined radio system. The radio transceiver translates digital data into analog signals, while the software controls the radio transceiver through the computer [11]. An antenna unit, RF tuner, analog-to-digital converter, and digital-down converter are all common components of a radio transceiver. By modifying the RF front-end, software-defined radios improve efficiency and adaptability. They can be built as independent systems or as modules [9]. A software-defined radio computer analyzes and broadcasts radio signals, with software operating on the computer managing the radio and configuring parameters [1]. The computer software is essential for the software-defined radio to work properly.

Discussion of the hardware and software aspects of SDR

Software-defined radio (SDR) is an arrangement of software and hardware components that perform either a portion or all of a radio's operational functions using configurable software, also called firmware, that runs on configurable technology for processing. An article by Krishnan et.al describes software radio as a growing field of study for future wireless systems, which involves the digital processing of conventional radio transmissions. It discusses the tradeoffs of major software-radio technologies, the radio reference platform, and layered object-oriented architecture. The Research topics in this article focus mainly on layering, tunnelling, virtual machines, and intelligent agents [20].

Field-programmable gate arrays (FPGA), digital signal processing (DSP), general-purpose processors (GPP), customizable System on Chip (SoC), and other application-dependent programmable platforms represent a number of the different hardware platforms used for developing SDRs [19] [21]. The signal processing block, commonly referred to as the baseband programming block, is at the core of SDRs, which comprises the majority of the implementation's digital domain operation [16].

To carry out digital signal processing tasks, the program provides functionality and high-level abstractions. Without a prior understanding of the target hardware architecture, applications such as SDRs can be written and implemented on FPGAs using popular programming languages such as C, C++, SystemC, and MATLAB [22] [21].

The article by Akeela et.al discussed the progress in Software-defined Radio (SDR) technology, which allows for the operation of various wireless communication protocols without hardware updates. The authors discuss the increasing focus on programmability, flexibility, portability, and energy efficiency in cellular, Wi-Fi, and M2M communication. They survey state-of-the-art SDR platforms, discussing architecture, design trends, and development tools. The authors also compare existing SDR platforms and provide a guide for developers [1].

The tuning range of an SDR determines its performance, which runs from near DC to 6 GHz or 18 GHz for higher-performance devices [6]. The bandwidth refers to the quantity of spectrum acquired on a single channel, with the highest-performance SDRs providing a significant instantaneous bandwidth of 1 GHz to 3 GHz [17]. Before reaching the antenna, the signal passes through RF stages such as anti-imaging filters, mixers, IQ up-converters, attenuators, and gain amplifiers. Data packetization is provided across Ethernet optical lines using digital boards, with the highest-performing SDRs giving broadband throughput of 4 40/100 Gbits/s. The reference clock in high-end SDRs is typically a 10-MHz signal produced using a high-stability device [23] [24].

SDR enables the implementation of novel wireless capabilities and characteristics for current radio technologies without the need for additional hardware. To meet several demanding needs, such as high energy and economic performance, wireless technology such as ZigBee, BLE, and LTE, as well as improved Wi-Fi standards for loT and machine-to-machine communications applications, have recently been developed [25] [6] [16] [14]. To support different standards, a wireless transceiver must be adaptable, reconfigurable, and programmed.

III. Advantages And Benefits Of Software-Defined Radio

1. *Flexibility and adaptability in different communication scenarios*

SDR is a significant concept in the 21st century because it enables the production of radio devices that are capable of receiving and broadcasting updated radio methods simply by running updated software [13]. It may also be used to integrate many demodulation techniques and standards into the same device, making upgrades simple. SDR is a wireless protocol technology that enables rapid upgrades and reprogramming without the need for hardware replacements [6]. It allows for the development of multi-band and multi-functional wireless devices. Network compatibility, flexibility for future upgrades, and reduced hardware and development costs are all contributing to the rising demand for SDR [26].

The study of Software Defined Radio explores the various wireless advancements in the field of communication. In various articles under the core mention of advanced technologies for a software-defined radio, it has been observed that it bridges the gap between discrete-time evaluations, hardware, software, and digital logic [22]. SDR is widely used in a variety of applications, such as national security, public safety, correlated automobiles, education, and scientific investigation [27]. The wireless community must comprehend its characteristics, benefits, and drawbacks. Because of its adaptability, low cost, and usefulness, SDR is a suitable alternative for developing wireless transceivers and networks that are suited to specific applications and performance needs [28].

2. *Cost-effectiveness and scalability compared to traditional radios*

When contrasted with conventional radio systems, software-defined radio (SDR) technologies provide greater adaptability, reconfigurability, and flexibility. SDRs are readily reconfigurable to support a wide range of wireless networking protocols, including Wi-Fi, Bluetooth, and mobile phone networks [21]. Software-defined radio, cognitive radio (CR), and cognitive networks (CNs) are all prospective adaptable network technologies that can be reconfigured. SDRs are customizable transceivers that may operate a variety of protocols for communication over wireless networks without the need for additional hardware [1] [7]. SDR advancements have resulted in a wide range of applications with an emphasis on programming capability, adaptability, convenience, and energy efficiency in mobile communication, Wi-Fi, and M2M communication systems [29]. SDR developers are seeking ways to improve the protocol for communication architecture and allow investigators to investigate prototypes on established systems [2].

3. *Increased spectrum utilization and improved signal quality*

Spectrum monitoring is constantly tracking and assessing the frequency distribution of radio waves to get essential data that is not accessible in the time domain. This information may be utilized for determining signal properties, including source separation, path, and modulating techniques [30]. Spectrum identification in software-defined radio can optimize the transmission of signals for ideal accuracy as well as durability by adapting to relevant radio frequencies and spectrum conditions. It might additionally employ cognitive characteristics for channel detection and intelligent spectrum distribution, allowing for more effective use of limited RF bandwidth [7].

Modern SDRs include an advanced FPGA-based computational backend, which increases reconfiguration and adaptability. This enables simple updates to the most recent radio standards and DSP techniques without requiring any kind of hardware modification [15]. The SDR is capable of intensive parallel computing, making it an effective foundation unit for spectrum monitoring systems. Direct transmission can shift data from the useful bandwidth to outside-of-the-band technology, increasing the efficiency of the spectrum [17] [30]. For devices that do not have immediate access to the wireless infrastructure, data rates and coverage can be enhanced. Because of the closeness of devices needing lower transmission powers, more energy efficiency may be attained [31].

IV. A Comprehensive Review Of Methods And Techniques For SDR

Software-defined radios are adaptable, may be changed to meet the requirements of the user, and are trustworthy in a wide range of conditions, particularly battlefield communication and broadcasting for commercial purposes [32]. SDR has several benefits, including being less expensive, using less power, and being resistant to disturbance caused by additional signals, making them ideal for inaccessible and urban regions such as railway stations and airports [33]. Through distinct modulating and multiplexing approaches, software-defined radios have developed over time, improving both their effectiveness and their performance. These strategies minimize interference and increase the strength of the signal, making it simpler to communicate in a variety of environments [34]. The modulation of frequencies is a popular technique for transmitting high-quality audio across great distances [25]. Another prominent approach is amplitude modulation, a technique that allows for minimal power transmission over considerable distances but is also exposed to disturbances and interference. Another technology, phase modulation, provides superior sound quality as well as quick data transfer. Time division, the multiplexing technique and approach used in electronic communication networks, enables multiple signals to be transmitted simultaneously, avoiding interference [34].

In the research work referring to the design of a QPSK communication system with Software-Defined Radio (SDR), the author explains SDR as an adaptable and easy-to-update platform that employs software to manage digital signal processing inside a communication system [35]. The system is linked to the USRP B210 through MATLAB and Simulink software blocks labelled "SDR Transmitter" and "SDR Receiver." In the modelling and measurement part, the QPSK model of communication is utilized, with connectivity from the transmit side to the receiver side. The technology is being tested at 4 GHz frequencies using equipment such as antennas. The results demonstrate that the communication system may be constructed on the SDR communication platform while achieving reliability criteria. Building a communication system with SDR is also versatile and simple to learn and implement [35].

In another work on the NOMA (non-orthogonal multiple access), the paper proposes a functional downlink NOMA system developed using the Open-Air Interface (OAI), a free and open-source software-defined radio technology. In this paper, the author describes a system that corresponds to LTE requirements and incorporates a receiving device with codeword-level consecutive interference elimination. For improving the efficiency of baseband processing of signals, a multi-thread processor approach is presented. For signal regeneration throughout the NOMA framework, an innovative DCI format is developed, and various higher-layer technologies in LTE systems are updated to provide application connectivity over the NOMA system. Over-the-air studies reveal that this NOMA scheme outperforms the orthogonal multiple access (OMA) strategy in terms of performance [36].

In another study on modulation strategy based on SDR, the research describes a viable Automatic Modulation Classification (AMC) system intended for use in real-time commercial applications. Using artificial intelligence methodologies, the system intends to design an algorithm that is reliable with minimal computing cost. The recommended design contains AMC signal characteristics as well as an ANN-based classification that conducts AMC over a range of SNRs. The combination of the hybrid and modular AMC systems is outperformed by the ANN-based classification algorithm, which is adaptable enough to broaden the modulation format information for various applications [37].

Further, a study on Transceiver design based on MIMO-SDR describes a cost-effective wireless communication system that includes a transmitter that transmits modulated data at an assigned carrier frequency of 2.45 GHz and a receiver module for filtering the signals and down conversion to intermediate frequencies [38]. For the final down conversion, the demodulation process, and the identification of incoming signals, the further processing component employs a DVB-T module and a free and open-source SDR. The combined use of all of these elements generates an adaptable, low-cost, software-defined communications system capable of recreating previously sent data [7]. Finally, software-defined radios provide several benefits, including flexibility, dependability, cost-effectiveness, and disturbance protection. It has proven to be a dependable and successful communication strategy in a variety of circumstances. The demand for them is expected to grow in the decades to come.

V. Applications And Use Cases Of Software-Defined Radio

1. Military and defence applications

Radar, military missile assistance, strategic radios, autonomous vehicle management, information warfare, and communication via satellite are all examples of military applications. Radio connectivity among military forces is essential for mission implementation, control and command, and data and information exchange [33]. Modern defence communications include real-time audio as well as video information transmitted throughout a network, with high-efficiency video encoding serving an important part in those operations. GNSS, or Global Navigation Satellite Systems, are critical in defence because they provide specific localization, surveillance, and navigation [39]. They assist the army in identifying enemy locations, friendly facilities, and additional locations of significance. GNSS may also be used for projectiles and autonomous vehicle orientation and navigation, particularly when travelling over unknown or hazardous terrain [17].

Another potential use of radio technology for defence is digital warfare and signal intelligence. Improved RF technologies, such as RF protection and frequency hopping, may assist in minimizing attacks by hackers on RF networks [27]. Signal intelligence intercepts and analyses transmissions from recognised and potential malicious sources. Radar identification, data transfer, and control and surveillance from a distance are some of the other use cases for radio communication systems in defence [23].

2. Commercial and civilian applications

SDRs serve as helpful devices utilized in a variety of sectors, including connectivity, defence communication systems, transportation, and research. They design effective and adaptable communication solutions that save the company resources while boosting customer service [32]. Because SDRs are easily reprogrammable to function with multiple frequencies and standards, they are helpful in military communications equipment and for controlling air traffic. They also give current updates on the position and status of flights [16]. SDRs are also used in scientific research to measure radio signals, analyse electromagnetic radiation characteristics, and create emerging wireless technologies such as 5G networks and IoT devices [40] [10]. Because of their versatility and efficiency, they are a crucial part of contemporary technological and communications systems. Overall, SDRs are an effective and adaptable instrument with several commercial and civilian applications.

3. Emerging and future applications

Investigation of different emerging and potential applications of software-defined radio (SDR) technological advances offers an extensive range of options for corporations of every type [27]. In the sphere of telecommunications, for example, SDR can improve flexibility in networks by delivering more effective and affordable communication options [32]. With tremendous possibilities, industries such as defence and aerospace may employ SDR to create novel communications technologies for military as well as civilian usage. SDR can also be used in the research and development of self-driving automobiles and robots, allowing for more accurate and dependable navigation and monitoring [21]. SDR might assist healthcare providers in constructing wireless surgical instruments that may track patient wellness as well as communicate data instantly, resulting in increased patient satisfaction and reduced healthcare expenditures [21]. Finally, SDR is capable of being used in the development of technologically advanced devices.

VI. Challenges And Limitations Of Software-Defined Radio

When it comes to using Software Defined Radio (SDR) systems, there are a few challenges and limitations that need to be taken into consideration. Some of the main concerns include security vulnerabilities, potential interference with existing radio infrastructure, and regulatory challenges that may arise when trying to adopt this technology [1] [14]. The key concern regarding SDR systems is the potential for security hacking and vulnerabilities. This is the main reason for the shift towards software-based systems as they may be more susceptible to hacking or other malicious attacks [26]. As a result, it's important to make sure that SDR systems are properly secured and that any potential vulnerabilities are addressed before they can be exploited.

Another potential challenge of SDR systems is compatibility with existing radio infrastructure. Because SDR systems can operate on a wide range of frequencies and protocols, they may not always be compatible with existing hardware or networks [16]. This can create interference and other issues that need to be addressed to ensure that SDR systems can be used effectively. Finally, regulatory and policy challenges may also arise when trying to adopt SDR technology. Regarding the use of SDR, different countries and regions may have different rules and regulations and it can be difficult to navigate these regulations when trying to implement SDR systems [39]. As a result, it's important to work closely with regulatory bodies and other stakeholders to ensure that SDR systems can be used safely and effectively.

VII. Recent Developments And Future Trends In Software-Defined Radio

Significant advances in SDR technology have occurred in the past few years, by enhancing the technology's capabilities while also rendering it more adaptable than ever before [16]. The recent transition to cognitive radio, which allows SDRs to dynamically react to fluctuating radio environments, serves as one of the most significant breakthroughs in SDR [7]. This has significantly increased the effectiveness and dependability of wireless communication, allowing SDRs to be used in various fields, ranging from smartphones to military communication. A further area of SDR development has been expanding SDR confidentiality and safety, especially defence and governance operations [7]. With a growing number of cyber risks involved, there is a greater demand for trustworthy and secure transmission solutions [21]. To safeguard confidential information from unintentional exposure, SDRs have been designed with extensive security features that include authentication as well as encryption methods. Investigators are looking for methods to make SDRs more sustainable and economical, in addition to ensuring security. As a result, innovative software and hardware designs have been developed to minimize energy usage and lower the total cost of SDRs [1]. SDRs are now more readily available to a broader variety of consumers as a result of these improvements. Looking ahead, analysts predict a further rise in SDR implementation, particularly in communication and the Internet of Things (IoT). As SDR technology improves, it is expected to play a significant role in shaping the future of wireless communication, enabling reliable, secure, and more adaptable communication systems [14].

VIII. Conclusion

SDR is an innovative technique that has transformed the communication sector by providing adaptability, effectiveness, and affordable solutions. It has proven to be a popular option for a variety of applications, ranging from military to commercial. Because of its versatility, SDR can adapt to evolving specifications by altering software rather than hardware, allowing it to handle various protocols and standards. As a result, it is an excellent solution for communication networks, which demand compatibility. SDR is also affordable since it does not require professional equipment and is available to a broader variety of consumers due to its usage of free, open-source software as well as affordable hardware. Real-time modifications to parameters, including frequency range, bandwidth, modulation techniques, and programming, enable improved performance, better signal quality, less disruption, and improved spectral efficiency. However, due to the complicated nature of the software that is utilized and the demand for particular expertise in areas such as digital signal processing and coding, SDR offers challenges in developing and operating SDR-based systems. Despite these limitations, SDR remains an important advancement in communication, with its adaptability, cost-effectiveness, and effectiveness making it a popular choice for an extensive spectrum of applications. As technological developments continue, SDR is expected to play a more significant role in shaping the future of communications.

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