Experimentations on the Transmit Power of a Universal Software Radio Peripheral Using GNU Radio Framework and a Handheld RF Explorer

Sunday Ajala\textsuperscript{1}, Emmanuel Adetiba\textsuperscript{1,2}, Mathew B. Akanle\textsuperscript{1}, Obiseye O. Obiyemi\textsuperscript{1,4}, Surendra Thakur\textsuperscript{4}, Joshua Abolarinwa\textsuperscript{5}

\textsuperscript{1}Department of Electrical and Information Engineering, Covenant University, Canaanland, P.M.B 1023, Ota, Nigeria

\textsuperscript{2}HRA, Institute for Systems Science, Durban University of Technology, P.O. Box 1334, Durban, South Africa

\textsuperscript{3}Department of Electrical and Electronic Engineering, Osun State University, Osogbo, Osun State, Nigeria

\textsuperscript{4}KZN e-Skills CoLab, Durban University of Technology, Durban, South Africa

\textsuperscript{5}Department of Telecommunication Engineering, Federal University of Technology, Minna, Nigeria

emmanuel.adetiba@covenantuniversity.edu.ng

Abstract. The Universal Software Radio Peripheral (USRP) and GNU Radio framework have a wide range of applications and are actively in use for teaching, research and for practical deployment of various trending wireless technologies. In this work, we explore the relationships between the power outputs of a USRP B200 device and its operating frequencies and USRP Hardware Driver (UHD) gains. These relationships are not precisely specified on the device datasheet, thereby hindering prompt design and experimentation decisions among Software Defined and Cognitive Radio (SDCR) researchers. A general purpose handheld spectrum analyser was engaged for recording the power outputs from the USRP B200 device within an experimental testbed that was setup for this study. The B200 device was driven by a GNU radio flowgraph designed for both wired and wireless modes and running on a general purpose host computer in the testbed. The results indicate that the output power decreases while the centre frequency increases, whereas the output power increases as the UHD gain increases from 65 dB until the device reaches the saturation point at 89.9 dB. These results provide a handy toolkit for SDCR researchers and practitioners.

Keywords — Cognitive Radio, GNU Radio, RF, Software Defined Radio, Transmit Power, USRPB200.
1. Introduction
The evolutionary trends in technology are changing the design and development strategies for radio devices, with Software Defined Radio (SDR) being at the cutting edge of the revolution in wireless communication domain. SDRs make it easy to perform many of the signal processing functions in software using various platforms such as USRP, SDR-LAB, HackRF, Noctar, RealTeck with USRP developed by Ettus Research being the most commonly used platform [1,2]. USRP has a wide range of applications and are still actively in use for teaching, research and practical deployment of various technologies. Some of these applications include but are not limited to energy detection [3], spectrum sensing [4], software based wireless transmission system [5] and Vehicle Power Line Communication (VPLC) [6].

The prominence of these tools is further established with experiments detailing applications in other interesting areas. In [7] for instance, the authors explored the viability of using GNU Radio; an open source SDR implementation and USRP to transmit and receive the OFDM radio signal with QPSK and BPSK modulations. The work investigated the Quality of Service (QoS) of the data transmitted in terms of the Packet Received Ratio (PRR). Another experience with the SDRs was reported in [8] and it is based on the use of two different software frameworks for integrated PHY-MAC development for SDRs. This report captures the use of the GNU Radio as one of the software designed to support PHY layer development, while Click was utilized as a framework for protocol development.

In spite of the extensive use of the USRP and GNU Radio, the exact specifications of the transmit power of USRP SDR devices is inaccessible. The absence of such specific information has induced a number of experimental studies in the literature. In [9], reports on the practical measurements of the output transmit power of a USRP board was presented and the performance of the system was also evaluated. In a similar experiment conducted by Zitouni and George [10], the analysis of the output power for a SDR device was carried out. The power measurement setup by the authors was made up of a USRP B210 and it was driven by a GNU Radio program. The result established the correlation between the output power and the central frequency, thus presenting a relationship that is inverse in proportion.

Despite the reported efforts in the literature and to the best of our knowledge, the output power specification of the USRP boards with respect to the operating frequencies and UHD gains in a wireless setup is unavailable. Thus, in this study, we setup an experimental testbed to measure and analyse (in both wired and wireless modes) the transmit power of a B200 USRP device with respect to the UHD gain over the operating frequency range of 70 MHz to 2.7 GHz and then from 4.85 GHz sweeping through to 6 GHz.

The rest of the paper is structured as follows: We provide an overview of the GNU radio framework and USRP in Sections 2.0. This is followed by Section 3.0 where we present the setup of our experimental testbed. The results obtained are presented and discussed in Section 4.0 and the conclusion is presented in Section 5.0.

2. GNU radio and universal software radio peripheral
The GNU Radio framework is a Graphical User Interface (GUI) based open source software development toolkit that offers signal processing blocks in a simulation environment similar to MATLAB/Simulink. It is widely used in academic and commercial fields to support both research on wireless communications and to develop real-world radio communication systems [10]. The signal processing blocks are written in C++ while Python is used as a scripting language for joining the blocks together into flowgraphs. GNU Radio is compatible with a number of RF hardware devices but it is primarily used with USRP [10]. As illustrated in Fig. 1. GNU radio framework provides a set of toolkits that allows signal displays and flow graphs to be built and run interactively.
Figure 1: A Screenshot of the GNU Radio Companion.

The family of USRP products includes a variety of models, which use similar architectures and comprises of two main boards, namely, the daughter board and the motherboard [11]. The Bus Series (B-Series) USRP boards are fully integrated single board SDR platforms with a continuous frequency ranging from 70 MHz to 6 GHz and a high speed USB 3.0 port interface for receiving and/or transmitting data from and to the host computer. The B-series are available in two different sizes: 9.7×15.5×1.5 cm for B200 and B210 USRP boards, and 5.1×8.3× 0.8 cm for the B205 mini and B200 mini, which are smaller versions. These boards all have a tunable bandwidth that ranges from 200 kHz to 56 MHz [1].

The USRP B200 utilised in this study is a Single Input Single Output (SISO) board with a Spartan 6 Field Programmable Gate Array (FPGA) and analog AD9364 transceiver. It also has a wide channel bandwidth of 56 MHz, and can be operated either in Frequency Division Duplex (FDD) or Time Division Duplex (TDD) modes. In FDD mode, the SDR operates in full-duplex mode so that it can receive and transmit at different frequencies simultaneously, while in TDD mode, only half-duplex operation with defined time slots is possible [11]. All USRP series require a Universal Hardware Driver (UHD) to support platforms running Linux, MacOS, and Windows. UHD is used by numerous applications including GNU Radio, LabVIEW and MATLAB/Simulink. Conventionally, radio software uses specific libraries for specific USRP series. However, the UHD driver provides a unique Application Programming Interface (API) for all radio software. In this study, we utilised UHD with the GNU Radio software as employed in [13]. The USRP B200 board's transmit power is programmable through its hardware driver's UHD gain parameter, but how this power relates to the increase or decrease in the UHD gain and/or frequency is not defined precisely in the manufacturer’s datasheet. Rather, the transmit power is merely stated to exceed 10 dBm in the datasheet. So, USRP B200 is being used by researchers and educators for SDR based testbeds in wireless communication without precise information about its RF behaviour. However, accurate and precise knowledge of the device’s transmit power especially in a wireless scenario is required in most applications for better practical implementation, especially for low-link margin wireless radio communication [1].

3. Experimental testbed

Fig. 2 contains the pictures of the experimental testbed for this study. The setups (a) and (b) consist of a laptop PC running GNU Radio Companion 3.0, a USRP B200 board, and a handheld RF Explorer spectrum analyzer connected to a Windows PC USB port, which runs the RF Explorer for Windows PC Client tool [14]. A GNU Radio flowgraph using the host laptop computer was designed and the flowgraph generates sinusoidal signal (continuous waves) with sliders to change the frequency and amplitude parameters of the signal [15]. Due to resource constraint, the general purpose handheld RF Explorer model utilised for this study has a frequency rating of 15 MHz to 2.7 GHz and 4.85 GHz to 6.1 GHz [14], which partly covers the frequency range for the USRP B200 (70 MHz to 6 GHz). The RF Explorer spectrum analyser was used to carry out both wired and wireless measurements within its spectrum coverage range. For the wired measurement, the USRP B200 TX/RX antenna port was connected to the spectrum analyser via a piece of Speedflex 142 cable. The cable is a 66 cm long Habia coaxial high frequency cable with a negligible attenuation of about 0.125 dB at 150 MHz and 1.504 dB at 6 GHz. These attenuation values were taken into account in our consideration of the outcomes of the experiments.
In the wireless mode, we engaged the RF Explorer’s Whip Narrow Band Antenna and its Nagoya NA-773 Telescopic Antenna for 70 MHz to 2.7 GHz and 4.85 GHz to 6 GHz frequency sweeps respectively as well as the USRP B200 TX/RX antenna. Fig. 3 shows a flowgraph of USRP Source connected to a USRP Sink block. The USRP B200 was configured using the flowgraph in Fig. 3, to transmit a sinusoidal signals starting from a UHD gain value of 1 dB up to the maximum value of 89.9 dB. The RF power of the corresponding received signal at the RF Explorer over the coaxial cable was recorded and extracted in .csv format on the RF Explorer-connected Windows laptop. For each of these UHD gains, we swept the frequency bands covered by the general purpose RF Explorer through the centre frequencies starting from 70 MHz to 2.7 GHz and then from 4.85 GHz to 6 GHz. The frequency was stepped at 60 MHz intervals while the averaged data track mode was used to determine the power output extracted. Figure 4 shows a screenshot of the RF Explorer client software interface.

The effects of the UHD gains on the transmit power of the USRP B200 in both wired and wireless modes were measured and recorded for UHD gains of 65, 75, 80, 85 and 89.9 dB. At each of these specific UHD gains, the average received power at the handheld RF Explorer was estimated.

**4. Results and discussions**

From the experimental measurements, the transmit power of USRP B200 was found to be below 0 dBm for UHD gains between 1 dB and 60 dB, thus, the values for those settings were not recorded in the course of our experiments. However, the experimental results starting from 65 dB are herein presented and they are segmented into two bands namely, lower frequency band (70 MHz to 2.7 GHz) and higher frequency band (4.85 GHz to 6 GHz). Figures 5 and 6 show the plots of the output power versus frequencies for the wired experimental setup while Figures 7 and 8 show the plots for the
wireless setup for the six different UHD gains considered in this study (i.e. 65 dB, 70 dB, 75 dB, 80 dB, 85 dB and 89.9 dB).

![Figure 5: Lower Frequency Sweep (70 MHz to 2.7 GHz) for Wired Experimental Setup](image)

![Figure 6: Higher Frequency Sweep (4.85 GHz to 6.0 GHz) for Wired Experimental Setup](image)

![Figure 7: Lower Frequency Sweep (70 MHz to 2.7 GHz) for the Wireless Experimental Setup](image)

![Figure 8: Higher Frequency Sweep (4.85 GHz to 6.0 GHz) for Wireless Experimental Setup](image)

From the experimental measurements, the transmit power of USRP B200 was found to be below 0 dBm for UHD gains between 1 dB and 60 dB, thus, the values for those settings were not recorded in the course of our experiments. However, the experimental results starting from 65 dB are herein presented and they are segmented into two bands namely, lower frequency band (70 MHz to 2.7 GHz) and higher frequency band (4.85 GHz to 6 GHz). Figures 5 and 6 show the plots of the output power versus frequencies for the wired experimental setup while Figures 7 and 8 show the plots for the wireless setup for the six different UHD gains considered in this study (i.e. 65 dB, 70 dB, 75 dB, 80 dB, 85 dB and 89.9 dB).

The results obtained as presented in Figures 5 to 8 show that the output power of the USRP B200 is both frequency and UHD gain dependent. Power outputs and consequently the received power at the RF Explorer were found to fluctuate with changes in frequency. Notably, for the wired experimental results, the power outputs at the UHD gain of 89 dB was below 10 dBm for 4.85 GHz to 6 GHz. This
UHD gain also generated the least set of power outputs for the 70 MHz to 2.7 GHz frequency range as shown in Fig. 6. However, the UHD gain of 65 dB generated the highest power outputs for the two frequency bands as shown in Figures 5 and 6.

Generally, the output power obtained for the wireless experimental setups presented power outputs (Figs. 7 and 8) that are lower than that of the wired setup with a difference of approximately 21 dBm at the peak values. Apparently, this loss in power was due to noise, distance and a higher attenuation in the wireless transmission channel than we had with the coaxial cable used in the wired setup. For the wired connection, the transmit power was found to be highest at 71 dBm at a central frequency of about 840 MHz and this peak value decreases as the frequency increases from 820 MHz to 2.7 GHz and then from 4.85 GHz to 6.0 GHz. While in the wireless measurement, we obtained 49.9 dBm as the highest output power at 1.44 GHz, which also decreases with increase in frequency.

More so, a fascinating observation from the plots in Figs. 5 to 8 is that the transmit power levels of the USRP B200 greatly fluctuates over the frequencies at lower UHD gains. It is noteworthy that the USRP B200 transmitter impedance matching is one of the reasons for the decrease in the transmit power at higher frequencies. The device is best matched and optimized at low frequencies (than at high frequencies), because the frequency increases the various matches of the transmission chain passing through different gain and noise circles on the Smith chart, which consequently affects its efficiency.

Although, the peak potential for the covered bandwidth is said to be more than 10 dBm from the Ettus research datasheet, we found experimentally that this specification is valid only for frequencies with high UHD gains from 65 dB to below 89.9 dB [11] similar to earlier results for wired measurements [9,12,15]. However, this study extends the literature [9,12,15] through an empirical determination of the USRP B200 power outputs as a function of the UHD gains within a wireless measurement setup. This is important because the use cases for SDRs are principally in wireless communication application domains such as satellite communication, spectrum sensing and cellular communication systems among others [3, 4, 16,17,18].

5. Conclusion
The evolutionary trends in technology are changing the design and development strategies for radio devices, with Software Defined Radio (SDR) being at the cutting edge of the revolution in wireless communication domain. SDRs make it easy to perform many of the signal processing functions in software using various platforms such as USRP, SDR-LAB, HackRF, Noctar, RealTeck with USRP developed by Ettus Research being the most commonly used platform [1,2]. USRP has a wide range of applications and are still actively in use for teaching, research and practical deployment of various technologies. Some of these applications include but are not limited to energy detection [3], spectrum sensing [4], software based wireless transmission system [5] and Vehicle Power Line Communication (VPLC) [6]. The relationship among frequencies, power outputs and UHD gains in USRP B200 device both in wired and wireless scenarios have been presented in this paper using an experimental testbed. In the future, relationships among these parameters will be explored for other SDR devices.

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