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VERY-LOW COST UNDERSAMPLING SOFTWARE RADIO RECEIVER: A PROOF-OF-CONCEPT IMPLEMENTATION

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This paper presents a proof-of-concept practical implementation for an extremely low-cost Software Radio receiver. An almost ideal, entirely digital radio receiver has been constructed at a very low price. The key concept that allowed the extreme reduction of the analog section of the receiver is the high factor undersampling technique. As a consequence, the complex and expensive analog section of conventional radio receivers is reduced to a band-pass filter and a programmable gain amplifier. The system was tested in real conditions with very good results.

Keywords: Software Radio, Undersampling, Nyquist rate, Radio receiver

1. Introduction

The current trend in radio systems is to reduce as much as possible the analog section of the transceiver and to implement as much as possible of the digital section in a programmable, reconfigurable manner [1]. This approach is named Software Defined Radio. The ideal version towards which this technology is heading represents the complete elimination of the analog section of the transceiver by extending the digital programmable circuitry right to the antenna terminals. This ideal system is named the Software Radio, indicating that all the functions of the various signal processing blocks that constitutes conventional radio equipment are implemented in software. The advantage of a completely programmable system stems from its unprecedented ability of being reconfigured at any moment. The main beneficiaries of this flexibility are the military [2] as well as the civilian telecommunications sectors [3]. The Software Radio technology lies also at the core of the Cognitive Radio paradigm which provides the solution for accommodating a continually increasing number of users in a finite available frequency spectrum by means of the dynamic spectrum management technique [4].

The Software Defined Radio and Software Radio platforms are also employed in radar applications giving rise to the concept of Software Defined Radar and Cognitive Radar [5].

The main impediment towards implementing Software Radio systems at decent costs especially at higher operating frequencies is the Nyquist-Shannon

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sampling theorem. It states that, in order to correctly capture an analog waveform, the sampling rate needs to be at least twice the frequency of the highest spectral component in the sampled waveform. As a consequence, the analog/digital and digital/analog converters and the programmable digital section of a Software Radio transceiver need to operate at very high frequencies, rendering the system extremely expensive or even impossible to build using current semiconductor technology.

This paper addresses this issue by employing a clever workaround, the so called high factor undersampling technique. This approach can be employed only for bandpass signals which, luckily, are exactly the signals used in telecommunications. In this case, the sampling frequency is correlated only with the bandwidth of the sampled signal, the condition being to use a sample rate which is at least double the bandwidth. As such, for the commonly used narrowband modulation schemes, the sampling rate and digital section speed constraints are drastically reduced, dramatically lowering the price and complexity of the transceiver [6]. Paper [7] presents a very flexible 5G development platform implementation based on undersampling.

As expected, this technique has its downsides, the most important being noise aliasing, which prevented the wide acceptance of this technique especially at high undersampling factors, where the sampling rate is many times lower than classical Nyquist sampling rate. However, papers [8] and [9] show that the impact of the noise contribution of the technique can be significantly reduced by intelligent designing. In order to prove the viability of high factor undersampling in Software Radio receivers a practical demonstrator has been constructed and tested.

2. Proposed system

The proposed solution consists of a radio receiver for the long and medium waves range, with an instantaneous bandwidth of approx. 50 kHz corresponding to 5 standard AM channels of 9 kHz. The block diagram of the proposed receiver is depicted in Figure 1.

The analog section consists of a band-pass filter (BPF) used for selecting the desired portion of the radio spectrum which will be further processed. The filter has a bandwidth of 50 kHz, a little less than half the analog-digital converter (ADC) sampling frequency. The second and last component of the analog section is the programmable-gain amplifier (PGA).

The digital section of the receiver begins with the ADC operating at a fixed sampling frequency of 119.047 kHz. The ADC is controlled by a microcontroller circuit which communicates with the computer trough a Universal

Asynchronous Receiver-Transmitter to Universal Serial Bus (UART to USB) converter.

The last and most important component of the receiver's digital section is the computer where all the digital signal processing needed for the radio operation is performed.

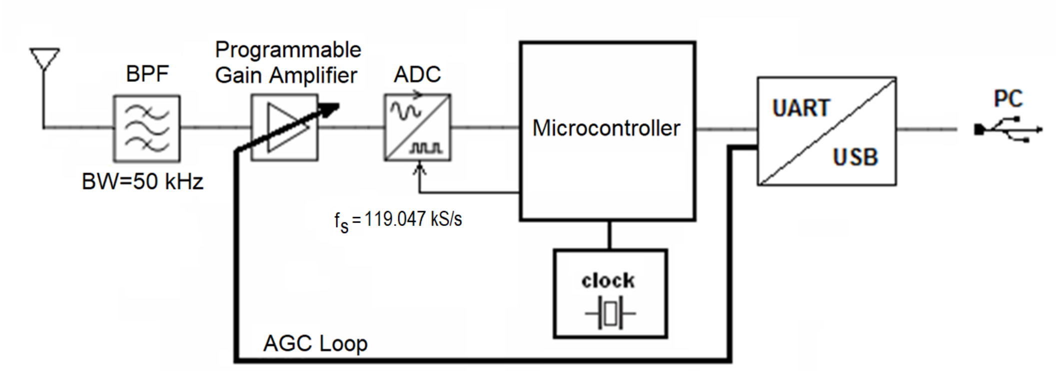

Fig. 1. Block diagram of the proposed system

The band-pass filter is implemented as a simple RLC filter (Figure 2). Its central frequency and bandwidth can be adjusted using the variable capacitor and the variable resistor.

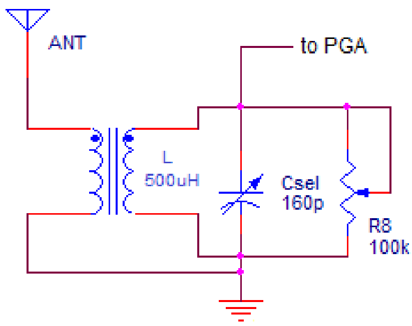

Fig. 2. Band-pass filter

The programmable-gain amplifier has a digitally controlled amplification in the range 11 to 231. It is implemented using 2 MAX4453 operational amplifiers. The first amplifier has a fixed AC gain of 11. It also implements the DC offset of the RF signal needed for single-supply operation. The second operational amplifier has a digital potentiometer in its feedback network allowing its amplification to be digitally controlled in the range 1 to 21. The schematic diagram of the PGA is depicted in Figure 3.

The ADC MAX153 needs an external voltage reference which has been implemented with a MAX6009 ultra-low-power 3V shunt reference and a TL082 operational amplifier, as shown in Figure 4. The voltage reference is also used for creating the DC offset needed for single-supply operation of the PGA.

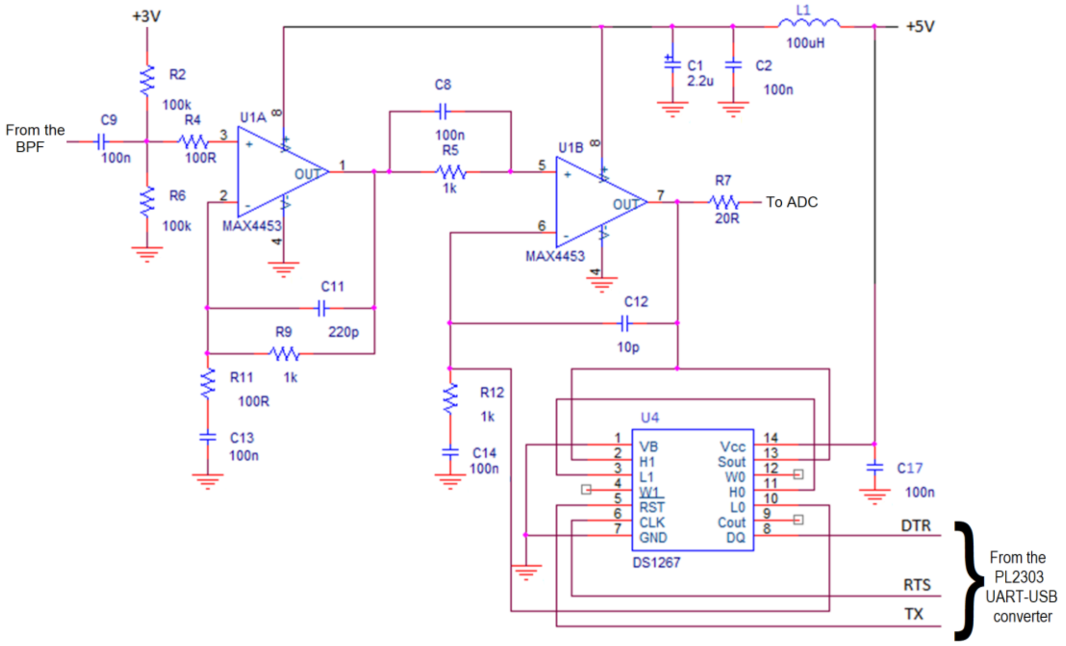

Fig. 3. The programmable-gain amplifier

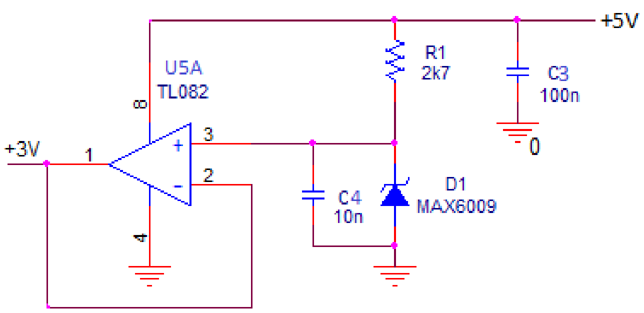

Fig. 4. The voltage reference

The digital section of the circuit consists of the MAX153 8bit ADC and the PIC16F628 microcontroller (Figure 5). The PL2303 UART-USB converter used in this setup is a commercially available cable integrated version.

The program executed by the microcontroller is extremely simple; it generates the clock impulse to the ADC and sends the conversion result trough its UART peripheral to the PL2303 converter in a continuous loop.

All the signal processing associated with the radio operation is performed on the computer, in a program created in LabVIEW.

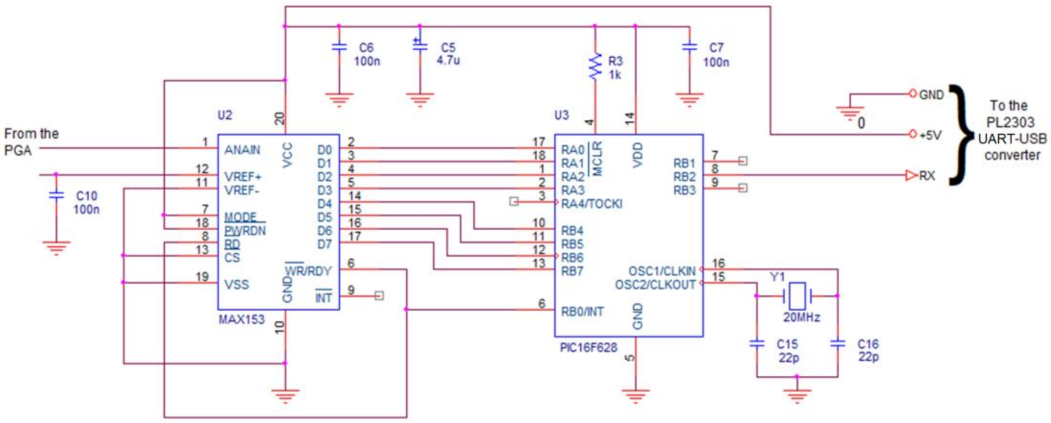

Fig. 5. The digital section

The computer program performs the Automatic Gain Control function by controlling the PGA and implements the selection and demodulation of the desired radio channel. Because all the signal processing is done in software the proposed system is a true Software Radio.

The graphical user interface of the computer program and the underlying block diagram (the visual code) are depicted in Figures 6 and 7.

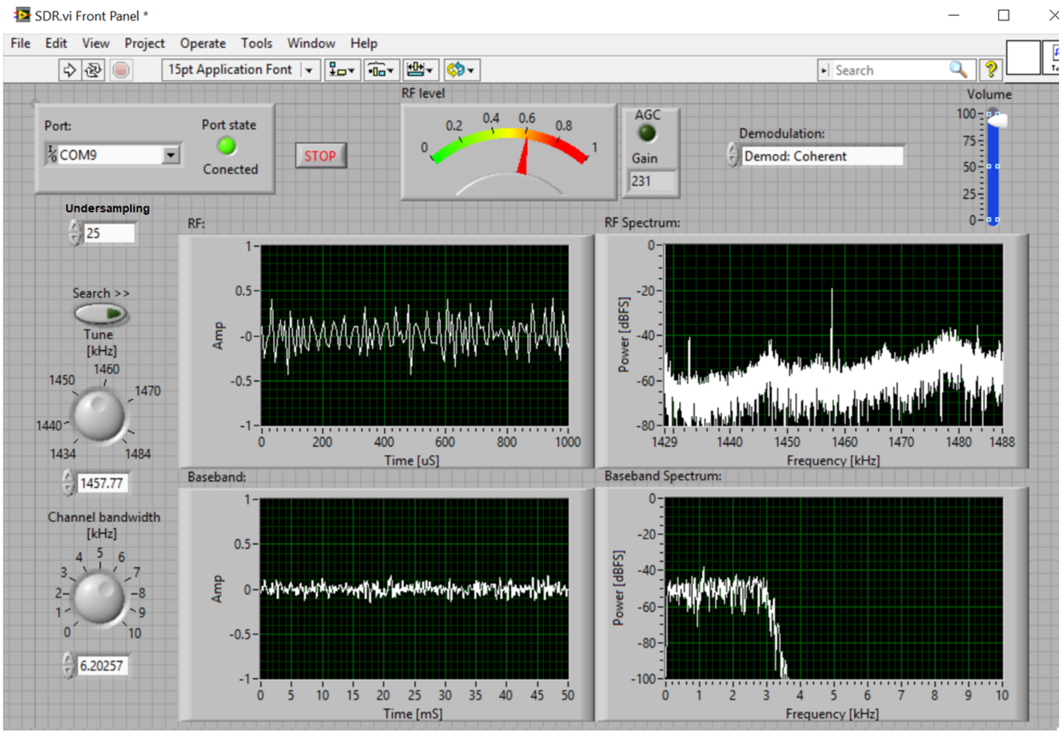

Fig. 6. The graphical user interface of the computer program

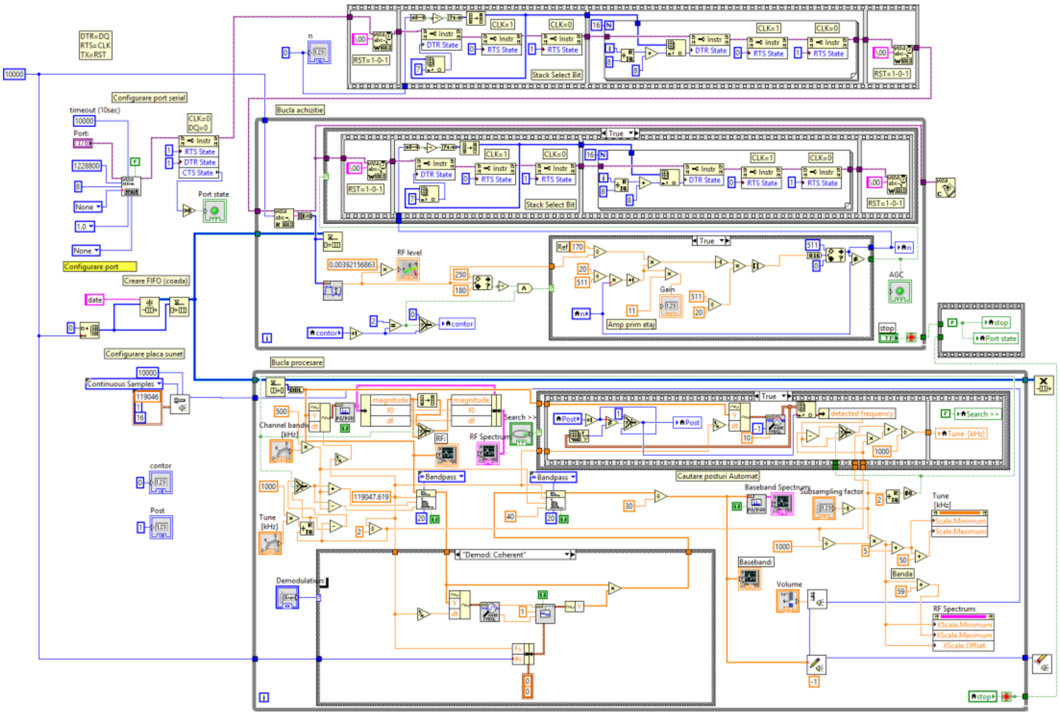

Fig. 7. The block diagram of the computer program

3. Results

The proposed system was tested in real world conditions and performed very well. It was employed for receiving an AM radio broadcast in the MW range. The receiver was placed at a distance of 14 km from the transmitter in an urban environment. The transmission frequency was 1458 kHz and the power 50 kW. Figure 8 shows the power spectrum of the digitized signal at the ADC output.

The noise floor lies at -55 dBFS while the signal power is -10 dBFS giving a SNR of 45 dB. The frequencies indicated in Figure 8, in order to simplify the operator's job, are the frequencies of the original RF signal as if they were measured at the input of the ADC. However, by employing the undersampling strategy, the ADC behaves as a mixer and down-converts the digitized signal. In our case, the frequency of the digitized RF channel, after the ADC, is:

$$f_{RF} - (N\text{-}1) \cdot f_s / 2 = 1458 \text{ kHz} - 24 \cdot 119.047 \text{ kHz} / 2 = 29.436 \text{ kHz} \qquad (1)$$

where f_{RF} is the frequency of the received signal, N is the undersampling factor and f_s is the ADC sampling frequency. N=1 corresponds to Nyquist rate sampling. In our experiment N = 25, a very high undersampling factor.

Compared to the implementation presented in [6] the proposed system is much simpler and cheaper, approximately reducing the complexity and manufacturing costs by half, while maintaining satisfactory performance for specific applications like AM radio receiving.

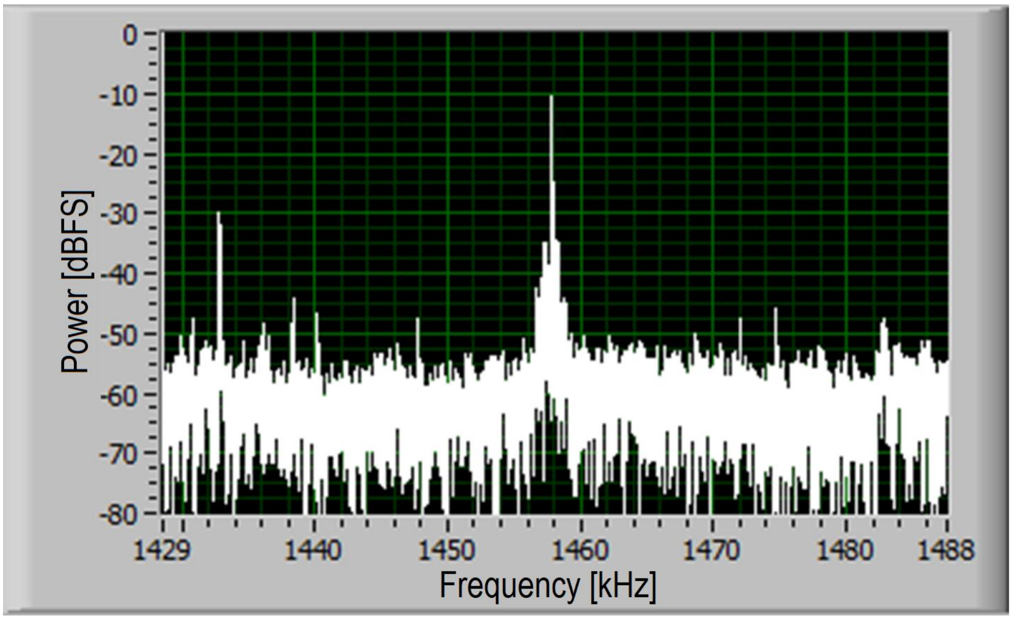

Fig. 8. The power spectrum at the ADC output

6. Conclusions

The experimental system presented in this paper demonstrates that the undersampling strategy is a solution for diminishing the costs of Software Radio receivers. The proposed solution performed very well even at high undersampling factors and low ADC resolutions (8bit). In the future, the system can be improved by increasing the ADC resolution which will lower the sampling noise.

R E F E R E N C E S

[1]. *M. Dardaillon, K. Marquet, T. Risset, A. Scherrer,* Software Defined Radio Architecture Survey for Cognitive Testbeds, Universite de Lyon, Inria, INSA-Lyon, CITI, F-69621, Villeurbanne, France, URL: http://arxiv.org/pdf/1309.6466.pdf

[2]. *C. Bergstrom, S. Chuprun, S. Gifford and G. Maalouli,* "Software defined radio (SDR) special military applications", in Proceedings of MILCOM 2002, **vol.1**, Anaheim, CA, USA, 2002, pp. 383-388, doi: 10.1109/MILCOM.2002.1180472.

[3]. *D. Sinha, A. K. Verma and S. Kumar*, "Software defined radio: Operation, challenges and possible solutions", in Proceedings of 2016 10th International Conference on Intelligent Systems and Control (ISCO), Coimbatore, 2016, pp. 1-5, doi: 10.1109/ISCO.2016.7727079.
[4]. *J. Mitola*, "Cognitive radio for flexible mobile multimedia communications", in Proc. IEEE Mobile Multimedia Communications Workshop, 1999, pp. 3-10.
[5]. *S. Haykin*, "Cognitive radar: a way of the future", in IEEE Signal Processing Magazine, **vol. 23**, no. 1, Jan. 2006, pp. 30-40.
[6]. *N. Matsumura, T. Toeda and M. Muraguchi*, "A new RF quadrature undersampling technique for an ideal software-defined radio system", in Proc. of 2010 Asia-Pacific Microwave Conference, Yokohama, 2010, pp. 1276-1279.
[7]. *Bob Muro*, "Using a COTS SDR as a 5G Development Platform", in Microwave Journal, 62 (2), February 13, 2019.
[8]. *M. Dahlbäck*, Implementation and Evaluation Of An RF Receiver Architecture Using an Undersampling Track-And-Hold Circuit, Master's Thesis, Institutionen för systemteknik, LINKÖPING, 2004.
[9]. *B. Staufenbiel, O. Lambert and M. Krist*, "Noise Figure Verification and Optimization of an Undersampled Software Defined Radio Based Radar Receiver for a Phased Array Radar System", 2018 48th European Microwave Conference (EuMC), Madrid, 2018, pp. 894-897.