SCA COMPATIBLE SOFTWARE DEFINED WIDEBAND RECEIVER FOR REAL TIME ENERGY DETECTION AND MODULATION RECOGNITION

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ABSTRACT

In this paper, a low-cost SCA compatible Software Defined Wideband Receiver (SDWR) prototype is described. The SDWR consists of off-the-shelf basic hardware components and a sophisticated software component. It is designed to detect and recognize an RF signal using Automatic Energy Detection (AED) and Automatic Modulation Recognition (AMR) software algorithms, developed by LOG.IN, in conjunction with common SCA compliant waveforms. The AED operates a real-time, blind wideband search of the electromagnetic energy, whereas the AMR identifies the parameters of a specific detected energy. The main focus of this paper is the integration of the hardware and software using SCA compatible devices and resources. The hardware includes a WiNRADiO Wintuner front end with an Ettus Inc. USRP device connected to a COTS laptop computer. The radio controller and waveforms are all developed in software using the CRC SCARI ++ suite and wrapping the LOG.IN AED and AMR resources for SCA compatibility.

1. INTRODUCTION

The software defined wideband receiver (SDWR) prototype work discussed here was completed for a project between LOG.IN of Roma Italy (LOGIN), and the Communication Research Centre of Canada (CRC). It is designed to detect, tune to, and demodulate a RF signal that belongs in the 20 to 3000 MHz range. It detects the signal of interest (SOI) with the Automatic Energy Detection (AED) function; discovers the modulation type of SOI using the Automatic Modulation Recognition (AMR) function; and with the AED and AMR tune to the exact signal and demodulate the SOI with one of the SCA compliant waveform functions (FM, AM, or CW).

The main objective of this project was to develop SCA resources and devices to meet the wideband receiver requirements for a third-party client. These requirements included the use of an off-the-shelf computer, such as a laptop or desktop, running Pentium IV chips or better, and a
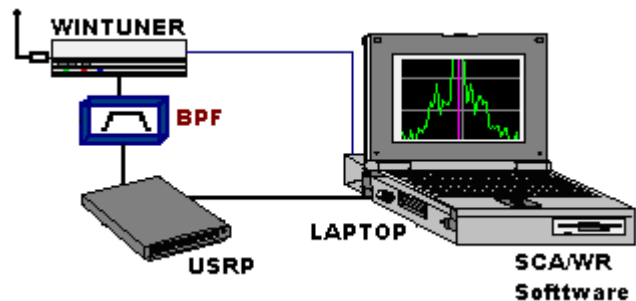

Figure 1: SCA Compliant SDWR Prototype

WiNRADiO WR-G526e/SC tuner (Wintuner) for wideband detection. Therefore, the focus is on the integration of the Wintuner, and the laptop with a low cost ADC device that can support the SCA devices and resources, so as to have a versatile SCA compliant SDWR (Figure 1).

2. SDWR SYSTEM OVERVIEW

The SDWR is split in two sections for the purpose of simple analysis: the SDWR Front-End and the Host Receiver PC (Figure 2). As in seen in Figure 1, the SDWR consists of four major hardware components: the Wintuner, a Band Pass Filter (BPF), the Ettus Inc. USRP, and a laptop. All CRC and LOGIN (SCA/WR) software reside on or Host receiver PC or laptop. The other components form the SDWR front-end.

Signals of Interest (SOI) in the 20-3000 MHz range are detected and downconverted by the Wintuner. This IF is then fed to the USRP for analog to digital downconversion via the appropriate digital down-converter (DDC) Channel of the USRP. The DDC signal is then forwarded via USB to the Host receiver PC (Figure 2), where the signal processing and waveform analysis is done in software using a general purpose processor (a Pentium IV processor for this prototype) [1]. Figure 2 shows the functional layout and flow between the various components of the SDWR in block diagram fashion.
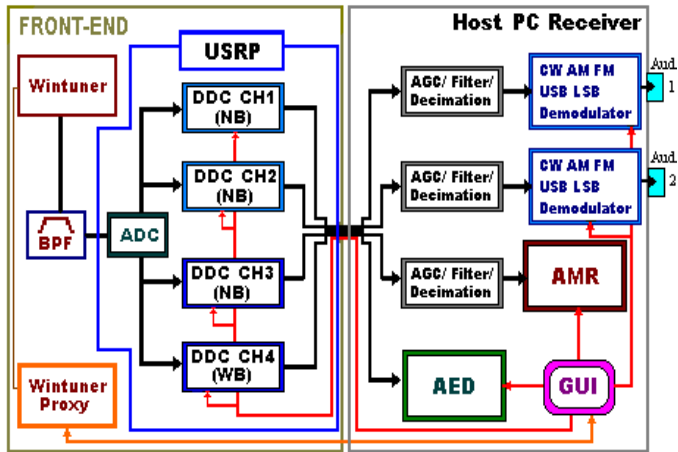
Figure 2: SDWR Block Diagram Layout

Figure 3: Part of GUI display depicting the SOI observed

From the GUI (Figure 3), the user can click on the desired SOI or choose the alarms that need to be investigated. The chosen SOI will then be sent to the AMR application (via another DDC channel) for modulation recognition. Based on the AMR results, the radio will then choose one of the two remaining narrow band (NB) channels to decipher the SOI, automatically calling up the resources needed to demodulate and listen to/record the signals data or information.

2.1 SDWR Front-End

The SDWR Front-End contains the Wintuner [2], the BPF, and for the purposes of this paper, the USRP [3][4]. SOI are detected by the Front-End, digitally downconverted, and forwarded to the Host Receiver PC or laptop (Figure 2).

The Wintuner is a 20-3000 MHz single channel tuner for use as a low cost wideband receiver, detecting signals in the range of 20-3000 MHz. It provides an IF at 21.4 MHz, with a BW around 32 MHz. Due to the relative large BW, sending this IF directly to the USRP can create aliasing and deteriorate the SNR and overall sensitivity of the SDWR. To avoid these issues and improve the SDWR performance, a BPF was added prior to entering the USRP. The BPF provided the USRP with a 21.4 MHz IF with a 3-dB BW of 16 MHz, and a sharp cut-off at 22MHz. This way unwanted spurs were also reduced, and aliasing was avoided.

The filtered analog IF goes through the USRP to be digitally downconverted. From the 16 MHz BW of the IF signal, a spectrum of 250 to 500 kHz are sampled at a time. Four channels are output from the ADC (see Figure 2). This allows four separate signal extractions from within the spectrum sample. Specifications asked for three channels to be of narrow band (NB) type (25kHz), and one channel to be wideband (WB) (>250kHz) used to forward the user defined spectrum sample to the AED application for energy

detection and signal intelligence (SIGINT) activities. The signal parameters (center frequency, bandwidth, and modulation) belonging to the SOI detected by the AED would be used to set the third NB channel that sends a real component signal to the AMR module.

However, some of the USRP DDC parameters are common for all channels [5], and therefore only one decimation rate can be used. In the case of our SDWR prototype, this would mean all channels (3 narrowband and 1 wideband) had to have the decimation rate required by the wideband channel. This however increases the amount of data processed by the Host PC Receiver, increasing processor utilization and limiting the amount of BW the AED can handle. Each narrowband channel required CIC (cascaded integrator-comb) compensation filtering and resampling because of this decimation limitation.

Once the SOI modulation type has been recognized, the SDWR then selects an available NB DDC channel for the digital downconversion and forwarding of the signal to the Host PC for processing. At any time, two SOI can be processed simultaneously.

2.2 SDWR Host PC Receiver

The Host PC Receiver (Figure 2) is a COTS laptop (Figure 1) running a Pentium IV 2.8 GHz processor. It is here that all the software resources reside, and the digital processing of the SOI occurs. The Host Receiver PC runs a Linux platform, and contains the CRC's SCARI++ SCA core framework, all the code necessary to run all the waveform applications, and the Java-based SDWR GUI allowing the end-user to configure the receiver as needed. The Wintuner is connected to the Host Receiver via a TCP/IP connection, while the USRP is attached via USB 2.0.

Once the DDC SOI enter the Host Receiver PC, they are put through the appropriate gain, filtering and decimation functions before demodulation (Figure 2). Two of these carry the FM, AM or CW signals that are to be independently demodulated and listened to on speakers. The other two carry the signals to be processed by the AED and AMR resources.

The initial spectrum sample (wide BW of 250 kHz or greater) exits channel 4 of the USRP and is processed using the AED application. Based on its calculations, an alarm is triggered, and the alarm defines which SOI will pass through Channel 3 for modulation recognition using the AMR application. Once recognized, the receiver calls up the necessary resources to deploy the proper waveform modules that will process and demodulate the SOI, so it can be listened to over the Audio device (i.e. speaker).

3. SCA COMPONENT BASED WAVEFROM DEVELOPMENT FOR THE SDWR

CRC has developed techniques in waveform design that allow for easier development, integration and testing. Signal processing algorithms are usually designed and tested in Matlab. Once the algorithm is proven, the signal processing functionality is placed in a separate C++ class that is tested on the platform of the developer's choice (usually with the same test vectors used in the Matlab testing). When the signal processing class is fully tested, this functionality is wrapped into a resource by using the SCA Architect (CRC SCA tools) to generate the resource. Final testing is done using a test waveform application including this newly developed resource.

The purpose of wrapping a signal processing class is to allow the separation of the signal processing from the details necessary to incorporate it into the SCA resource. When the signal processing is in a separate class, it can be developed and tested independently of the software radio environment. More importantly, it can be developed on the platform of choice of the algorithm developer. This allows the algorithm developer to do the work with only very limited knowledge of the target software defined radio.

CRC design conformance is not particularly onerous. Some of the key guidelines are:
- must support a data processing entry point that includes an input data array and size, while returning an output data array and size
- any input array is read-only
- any returned data array must be allocated by the class and will not be deleted externally
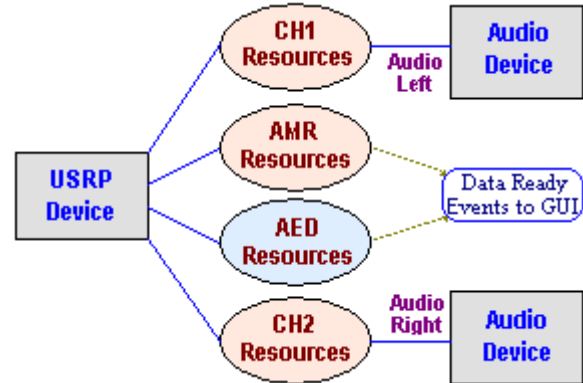

Figure 4: SDWR Devices and Resources

- get and set functions must exist for all externally visible members that will become properties of the resource
- must support an initialization entry point that performs all initialization including any initial memory allocation

In Figure 4, a simplified overview of SDWR Receiver from the SCA perspective is provided. The USRP device abstracts the hardware receiver from antenna to downconverter. The USRP device has four channel outputs, three narrowband and one wideband. Each output is connected to various portions of the waveform. The four channels include two narrow-band demodulations channels (CH1 and CH2), one narrowband demodulation detection channel (AMR) and one wideband energy detection channel (AED). The demodulation channels can produce audio that is sent to the Audio Device. This Audio Device abstracts the stereo output of a sound card and speakers in the host computer. The output of the AED and AMR are sent to the GUI using SCA events.

3.1 AED and AMR

As previously stated the goal of the AED and AMR waveform is to detect and classify some SOI in the 20 to 3000 MHz range.

The basic building blocks of the AED waveform are presented in Figure 5. It consists of an FFT filter bank that transforms the input data stream to the frequency domain. The FFT processor is of a fixed dimension (1024 points) and uses a Hanning window. A coarse estimation of the power spectral density (psd) is then computed by the squared value of the FFT bins. The psd estimation is the input for a custom spectral smoother developed by LOGIN. This smoother has a set of customizable parameters that set the behavior according to the RF scenario. The smoothed
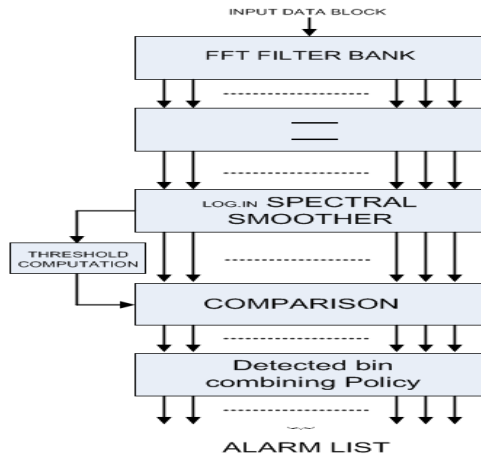
Figure 5: AED Resource Block Functionality Chart

Figure 6: SCA Receiver Channel Resource Component Overview

psd is used, following pre-customized criteria, to set a detection threshold. If the power level of a bin exceeds the threshold that bin is declared to be "alarmed". While a detailed description of the various processes of the module is out of the scope of this paper, the simplified outline is adequate to understand its role within the SDWR.

The Automatic Modulation Recognition (AMR) waveform has to classify the SOI after their detection. LOGIN developed this waveform to recognize both analog and digital modulation (CW, AM, FM, H3E±, J3E±, M-FSK, M-PSK) without any a-priori information about the signal type. The only information that AMR needs is the input signal bandwidth that is provided by the AED waveform. The AMR acts in a tree decision scheme. For each step being computed, a threshold comparison of various options is used to determine the proper modulation type.

The main challenge from LOGIN in the SCA wideband receiver development has been the porting of already existing waveforms in a components oriented environment. The AED and AMR waveforms are originally developed like a big monolithic application with graphic interface running on the MS Windows environments only. To allow the integration of AED/AMR waveforms in the SCA architecture, LOGIN has slightly modified its waveforms according to the coding guidelines provided by CRC as described in section 3.

3.2 AM, FM and CW Waveforms

The channel 1 and channel 2 resources are actually a set of resources that can demodulate AM, FM and CW type waveforms. The resources used and their relationship is shown in Figure 6.
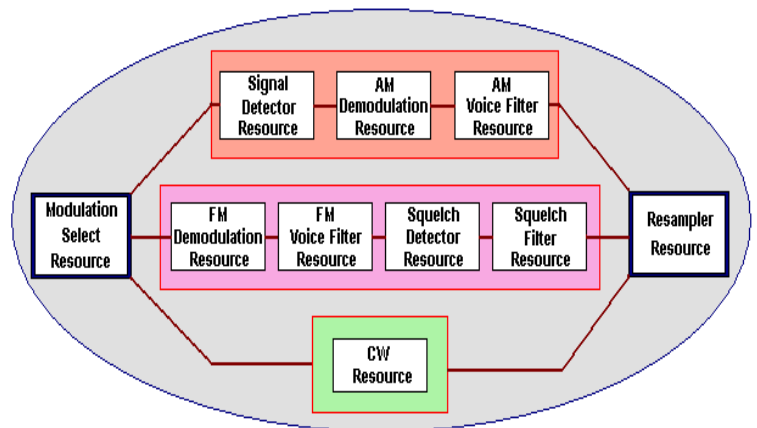
The desired modulation type is selected using the modulation selection resource, which then forwards the signal to one of the set of resources for demodulation of AM, FM, or CW. Note that CW demodulation is actually no demodulation at all. It just acts as a pass through - the output of the real component of the complex input. When the signal processing is complete, the digital signal is resampled and sent to the audio device for listening/recording. All of this is done in software, using SCA compliant resources.

The AM and FM waveforms had previously been developed for a demonstration platform. Some shortcuts had been taken in the waveform's early development. These shortcuts were found to be unacceptable when porting to the USRP platform. These shortcomings were corrected in the AM and FM resources allowing the new resources to more general purpose and more portable.

3.3 Wideband Receiver User Interface

The user interface of the SDWR is a generic Java-based GUI developed by CRC and specialized by LOGIN. Existing graphical windows from a previous development were ported to the GUI. An SCA event was created, generated by the AED, which the GUI subscribed to regarding new spectrum available for display. A similar event was generated by the AMR, and also subscribed to for modulation recognition.

The GUI also ensures name server, node and domain running (radio) are available. This way the GUI communicates with events, name server, node, domain manager and waveform assembly controller
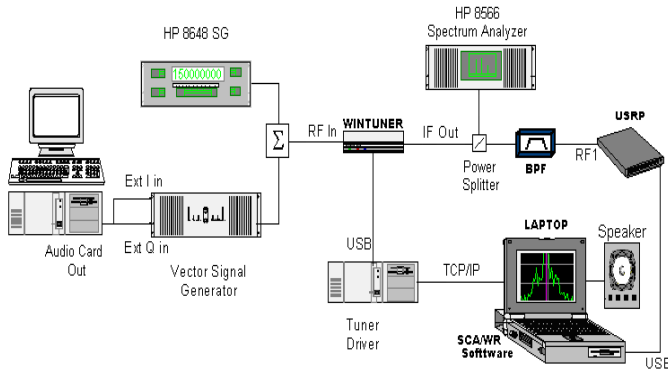
Figure 7: Overview of Test Set-up

4. SDWR TESTING

Test samples of the spectrum are performed, with focus on key user radio bands, such the narrowband public safety 150 MHz and FRS 465 MHz FM bands, the 122 MHz AM bands, and the wideband commercial broadcast FM bands.

For the majority of the spectrum, tests were done using signal generators with added FM modulation of a tone, or AM modulation, to observe Wintuner performance and the USRP ability to work with varying IF power levels. The test bed is shown in Figure 7. Tests were done concurrently at CRC in Ottawa, and at LOG.IN in Roma.

Apart from the SDWR prototype, a second PC was used to run the Wintuner Proxy. This was done because the Wintuner drivers were only available for Windows and the laptop was running Linux. Two signal generators were used to produce an RF signal carrying test data from various audio files. A spectrum analyzer was also used to verify signal inputs before entering the USRP. Results from the SDWR output were heard on the speaker, or recorded on the hard disk of laptop (for later analysis using MATLAB).

5. TEST RESULTS

Since no modifications are made to the internal components of the hardware, testing of the hardware is done to verify the hardware device specifications provided by the vendors. For example, the Wintuner performed as expected and within the specifications of the Wintuner user guide.

A total of 24 test cases, both software and hardware, were run as part of the Acceptance test procedure. Each Test case had a set of tests needed to be run and passed, before moving on to the next test case. While it is not possible to describe them all in this paper, we can say that the SDWR properly distinguished, recognized, and demodulated all the AM, FM, and CW waveforms. The SDWR also passed all test cases. However, some observations that may be of interest regarding the SOI detection and overall system performance of the SDWR and is discussed below.

5.1 SOI Detection Performance

In Figure 3, as part of the GUI, the spectrum display shows an example of the AED detection capabilities. The AED waveform is able to detect, in real time SOI present and estimate the correct bandwidth and central frequencies. Moreover this adaptive threshold makes the AED robust with respect to noise. Various tests have shown that AED functionality exhibits the same general behavior as the non-SCA implementation. The real limiting factor of detection performance is related to the smaller dynamic range due to the low ADC resolution (12 bits) [5]. This issue makes it difficult to detect weak signals in the presence of strong signals and, in some cases, incorrect estimations of the SOI bandwidth. The correct estimation of the SOI bandwidth and central frequency is a key issue for the AMR estimation performance.

5.2 SDWR Overall System Performance

Due to the ADC bit resolution limitations, the sensitivity of the device as a whole is reduced. After testing, it was observed that the SDWR has a Dynamic Range (DR) of around 62 dB, approximately 10dB less than the theoretical levels that can be achieved with a 12-bit ADC. Another observation was the AED maximum BW that could be processed at one time was 500 kHz, and was the maximum achieved due to processor limitations. However, tests showed that the greatest Dynamic Range and best processing success of SOI is achieved when the sample BW is set at 250kHz (as seen in Figure 3 GUI display). Future versions of the SDWR prototype will have faster processors to be able to handle higher BW rates and higher resolution ADCs to improve DR and sensitivity.

6. CONCLUSION

With the work done here, the LOG.IN AED and AMR have been integrated as part of the waveform of the Software Defined Wideband Receiver using the CRC SCARI++ core frame work and tools. Relatively low cost-off the shelf components were used to develop the SDWR prototype. The sensitivity and processing capability of the SDWR are very good for the cost. Most importantly though is the fact that the resources developed here can be easily reused and ported over other devices for faster development of newer and better versions of the SDWR.

7. FUTURE WORK

In light of the success of the SDWR prototype development, LOGIN will establish, in partnership with CRC, a signal-processing laboratory to develop civil and military SDR applications, based on the CRC SCARI++ SCA suite. These applications are mainly focused on radio spectrum monitoring. Also future versions of the SDWR that will work over a Windows based operating system rather than POSIX based are being worked on as well.

8. REFERENCES

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