Realization of a Flexible Technological Demonstrator for HF Sky-wave Data Links

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Abstract— Radio frequency range between 3–30 MHz is called high frequency or shortwave radio. For a long time, the high frequency band has been considered as the most important means for communications over long distance. The advent of new technologies, such as satellite and terrestrial communications, made the high frequency systems obsolete. Despite that, a new interest for these systems is growing due to the need of having a relatively cheap and simple system for data and voice exchange, which could be a real alternative to existing system in case of their failure. This paper aims to present an effective and flexible HF digital transceiver demonstrator based on the software defined radio paradigma. The purpose of this demonstrator is to maintain the "essential" information among the authorities in case of the failure of both satellite and Internet communications for critical scenarios (e.g., terroristic attacks, natural disasters).

1. INTRODUCTION

The High Frequency (HF) band lies within 3–30 MHz. This part of the electromagnetic spectrum provides several propagation modes such as ground wave, surface wave and sky-wave, which permit long haul communications. The HF communications have been used for many years. Throughout the 1960 and 1970, HF sky-wave systems were the core of the long distance communications. With the inception of the satellite communications in the late 1960, the HF systems were relegated to a back-up role. Indeed, the satellites represent a flexible solution for broadcasting and mobile applications; moreover they allow a provision of service to remote or undeveloped areas. Despite these advantages, the interest of the HF systems was increasing because of their ability to perform long distance connections without the need of using channel infrastructures such as repeaters or radio link, but simply using the ionospheric propagation. Therefore, despite a HF connection is characterized by a low data rate transmission, the absence of the support structures for the link establishment makes these systems much more reliable and robust respect to other systems. Indeed, both satellite and terrestrial communications are very weak to electronic attacks and to destruction events. These features make HF systems suitable to protect those infrastructures which are essential for the health, security and economic asset of the citizens as well as for the effective functioning of governments in European Union (EU) countries [1]. In this context, we propose a HF sky-wave technological demonstrator which exploits ionospheric propagation to exchange sensitive information among the European Critical Infrastructures (ECIs) when the Internet connection fails as the critical events occur. The consolidated technology in HF band enables the use of COTS and reliable hardware and software solutions for the realization of the demonstrator.

2. SYSTEM ARCHITECTURE

The system is realized via a hybrid technology (Figure 1), which combines techniques of Software Defined Radio (SDR) and analogue/digital components. The Band Pass Fiter (BPF), the Low Noise Amplifier (LNA) and the transmitting Power Amplifier (HPA) are implemented in analogue domain while the Analogue to Digital Down Conversion (ADC), the Digital Down Conversion (DDC), the Low Pass Filter (LPF) and data rate conversion, which is decimation, are carried out in the digital domain. A host personal computer (PC) manages and coordinates each operative stage as devices control and signal processing. Specifically it is devoted to perform the following tasks:

1. Universal Software Radio Peripheral (USRPs) control by using a Gigabit Ethernet interface.
2. Generation, modulation and demodulation of the transmitted/received signal;
3. Data acquisition and data reconstruction.

The Laboratory Virtual Instrumentation Engineering Workbench (LabVIEW) [2] programming language has been used for the realization of the HF demonstrator. This decision lies in the ability of this language to have user-friendly interfaces (called front panel) and to perform some tasks like acquisition, analysis, display, data storing and instruments control. Moreover, an extensive support for accessing instrumentation hardware, the presence of a large number of libraries, the possibility of code reuse without modifications and the possibility of creating stand-alone executable, make LabVIEW particularly suitable for a practical implementation of the HF demonstrator. It is important to underline that, the USRP plays a key role for both functioning and reconfiguration of the HF demonstrator. Indeed, the USRP is a software reconfigurable hardware and this feature together with a host PC, makes this choice an ideal solution for performing any kinds of RF band pass signal processing. Finally, referring to Figure 1, it is worth noting the presence of a LNA, which is a key component for the reduction of the noise at receiver. It is placed at front-end of the radio receiver in order to amplify very weak signal minimizing the injection of additive noise. For these reasons the LNA should have a high gain and a low Noise Figure (NF). The Mini Circuits ZFL-1000LN+[3]-Figure 2 characterized by an operative bandwidth which ranges between 0.1 MHz and 1000 MHz, 2.9 dB of Noise Figure and a 20 dB of gain, represents a good solution for the realization of the receiver chain in the HF band. The High Power Amplifier at transmitter is responsible for the amplification of the transmitted signal; the transmission gain should guarantee a sufficient Signal to Noise Ratio (SNR) at receiver. Moreover, it should be as linear as possible in the operative bandwidth, in order to minimize amplitude fluctuations [4]. Among all the HPA models, the BT00500-ALPHA-S-CW [5]-Figure 2 manufactured by Tomco Technologies is one the most suitable for our purposes. This amplifier is solid state technology throughout designed for amplifying continuous waves between 3 MHZ and 30 MHz with a peak power of 500 W. BPF at receiver is designed in order to reject out-of-band noise. A Global Position System (GPS) and a stable 10 MHz clock source can be used to synchronize the USRPs in the transmitter and receiver chains. This is essential in a HF real scenario where the transmitter and the receiver stations are located far from each other. Indeed, sky-wave links are typically used for long circuits which range from about 160 km up to 12000 km [6].

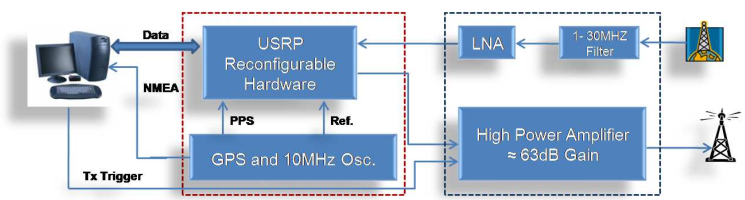

Figure 1: System architecture.

Figure 2: LNA (ZFL-1000LN+ model) and HPA (BT00500-ALPHA-S series).

3. LABORATORY TEST EXPERIMENT

The reliability of a HF radio transmissions is dependent on a large number of factors such as [7, 8]:

1. The propagation channel is space-time variable. The propagation behavior depends on the operating frequency, season, time of day, location and solar activity (identify by the Sun Spot Number — SSN) [9];
2. The HF spectrum is strongly crowded by communications and broadcasting transmission; therefore the number of free channels are limited and often available only for a limited time;
3. The strong presence of back-ground noise like atmospheric, cosmic and man-made. Internal noise is almost negligible [10].

Therefore the characterization and implementation of a HF radio link is a very complex matter. In a first instance, a simplified simulated scenario has been taken into account. The simulated scenario includes the following items:

1. Connection type: point-to-point;
2. Single carrier;
3. Phase-Shift-Keying (PSK) modulation.

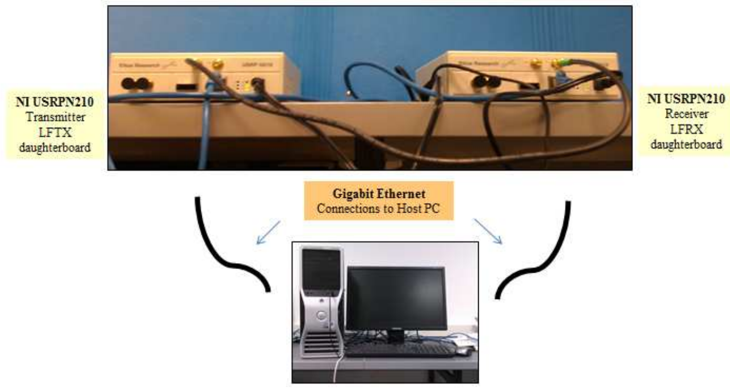

Figure 3: Simulation equipment.

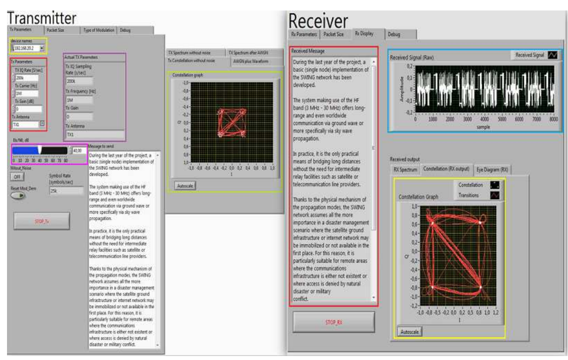

Figure 4: Transmitter and Receiver user interface.

Two USRP N210 [11] connected with the host PC through a Gigabit Ethernet connection have been used (Figure 3). The N210 consists of a Xilinx Spartan FPGA, 100 MS/s dual ADC, 400 MS/s dual DAC. These USRPs are equipped with LFTX [12] and LFRX [13] daughter-boards for transmitting and receiving HF signals. Signal processing, modulation/demodulation and USRPs control are performed by means of labVIEW programming language. The experiment implements a simple communication system for transmitting a text message making use of PSK modulation. Specifically, the message to be sent is converted to a bit-stream. After that, this bit-stream is organized in packets. Each packet consists of useful data and additional bits such as the synch bits and the guard bits. The synch bits provide a reference for synchronization and data validation (check the detected packet), while the guard bits protect against the filter effect. The data is then converted in the analogue domain and the base-band waveform is mixed with the carrier frequency for being transmitted by the USRP. At receiver the data is continuously acquired by the receiver. After demodulation, the guard bits are removed and the data bits can then be recovered. The packet number is used to organize the data in the correct order and allows the receiver to determine when all packets have been received. At this point the full text can be retrieved. This PSK demonstrator allows on the fly setting and selection of the main HF communication parameters. This is made possible by means of the LabVIEW interactive user interfaces (Tx interface and Rx interface — Figure 4). The following list summaries the main parameters that the user can define:

1. *Signal parameters (red box-left hand of the Figure 4)*: the signal parameters consist of the RF carrier frequency (in Hz), the baseband sample rate (S/sec), tha antenna gain (in dB), the connector name on the front panel device. It is important to underline that at the receiver,

these parameters must be forced to be equal to those of the transmitter. The same is true for the modulation parameters (yellow box-Figure 5) and filter parameters (pink box-Figure 5). These filters are important in order to reduce the amplitude and phase transition of modulated signal and to reduce the inter-symbol-interference (ISI). It is worth noting that the parameters should be choosen taking into account external environment, however it could happen that the used device cannot satisty those specifications. In this case, the USRP sets his parameters in order to try to satisfy the requirements and to comply its own technical specifications (see violet box-Figure 4);

2. *Device names (yellow box of the Figure 4)*: specifies the USRPs IP address;
3. *Packet size (yellow box of the Figure 6)*: this tab specifies the packet structure together with the bits number of each field that composes the packet. About the packet structure, the guard bits protects against the filter edge effect, the synch bits are used for the carrier and clock recovery and finally the packet number allows to reorder the packet and to detect missing packets. The length of the useful data is specified by the data field. In order to have a constant packet size and therefore to make easy the receiver configuration, a fixed number of the samples are appended at the end of the signal;

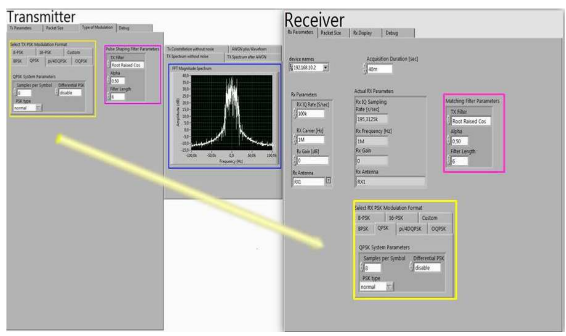

Figure 5: Transmitter and Receiver modulation interface.

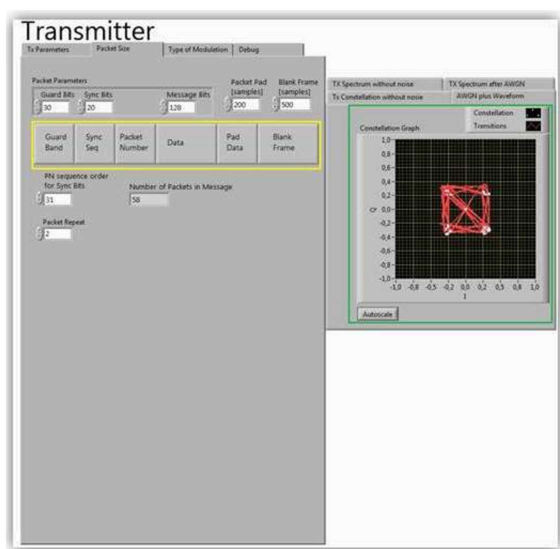

Figure 6: Transmitter and Receiver packet interface.

Although the experiment was conducted in a controlled environment, the insertion of a simulated zero-mean complex additive white Gaussian noise (AWGN), with uniform power spectral density, allows to reproduce a more realistic environment. This operation returns a signal-plus-noise waveform with a user specified E_b/N_0 (pink box-Figure 4), where E_b is the the energy per bit and N_0 is the noise variance. A number of plots are shown through the user interface, specifically:

1. *Transmitter (green box-left hand in Figure 4) and receiver (yellow box-right hand of the Fig-*

ure 4) constellation graph;

2. *The spectrum of transmitted base-band complex waveform with and without noise (blue box-Figure 5)*;
3. *The resulting message(red box-right hand of the Figure 4)*;
4. *Time-amplitude behavior of the raw-received signal (blue box-right hand of the Figure 4)*

4. CONCLUSION

In this paper the main concepts and results on the design of a demonstrator for HF communications have been described. The demonstrator is based on USRP N210 and LabVIEW programming language which guarantee a low cost and an extremely flexible solution suitable for SDR implementation. A preliminary laboratory test has been performed to validate the functionality of the system. The experiment has been focused on the PSK modulation. This demonstrator is designed to allow the main communication parameters to be changed on the fly. The effect of additive Gaussian Noise has been evaluated by using a set of different SNR. The system, equipped with the RF devices (e.g., antenna, LNA, HPA), could be tested in a real scenario without any modification. It is worth noting that in a real scenario, the communication parameters should be chosen according to the ionospheric channel and the external noise level. For this reason, the future developments aim to realize a fully automated system which integrates operations such as the spectrum management and the ionosphere monitoring in order to make the system able to adaptively operate in function of the scenario changes.

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