2nd URSI AT-RASC, Gran Canaria, 28 May – 1 June 2018

Low cost development of HF receiver prototype for HF-START field campaign

Kornyanat Hozumi* (1), Takumi Kondo(1), Susumu Saito(2),
Hiroyuki Nakata(3), Takashi Maruyama(1), Takuya Tsugawa(1) , and Mamoru Ishii(1)
(1) National Institute of Information and Communications Technology (NICT), Tokyo, Japan
(2) National Institute of Maritime, Port and Aviation Technology, Electronic Navigation Research Institute (ENRI), Tokyo, Japan
(3) Graduate School of Engineering, Chiba University, Chiba, Japan

Abstract

HF-START (HF Simulator Targeting for All-users' Regional Telecommunications) is a user-friendly simulator developed to meet the needs of space weather users. Because prediction of communications failure due to space weather disturbances is of high priority and must be reliable, HF-START is necessary to be evaluated. A simple and low cost prototype of software defined radio (SDR) based digital receiver is developed for the HF experiment to evaluate the HF-START during the field campaign. The field campaign employs the receiver prototype in addition to existing domestic ionospheric observations in Japan. The experiment allows analyzing the effect of the ionosphere on radio propagation delay. The first experiment has proven the capability of the low cost prototype as its result showed very good signal quality with loud and clear playback ability. Extending similar experiment to Southeast Asia is planned.

1. Introduction

Since the first RF transmissions era around 1890 [1], radio techniques have continually evolved in daily life providing users to stay connected. Many RF technologies have been developed. In fact, such RF devices are commonly limited in their functionality to the hardware components. Without accessing to the hardware itself, the devices cannot be reconfigured [2].

Nowadays, even though satellite communication is getting popular, HF radio is still an important means of communications. During severe weather, natural disasters, and space weather disturbances, many of better and more sophisticated solutions than HF fail. HF radio, which can propagate several ten to thousand kilometers, should be retained as the backbone of communications to remote areas. International Amateur Radio Union (IARU) and its members such as Japan Amateur Radio League (JARL) and Radio Amateur Society of Thailand (RAST) officially use HF band for emergency and disasters relief operation. The IARU is a federation of national associations of certified radio amateurs, representing over 150 countries and separate territories around the world [3]. By mirroring the structure of the International Telecommunications Union (ITU), the IARU classifies the world into three regions. The IARU Region 1 covers Europe, Africa, the Middle East and Northern Asia. The IARU Region 2 covers the Americas. The IARU Region 3 covers Asia-Pacific. This paper focuses on the IARU Region 3.

Because many of amateur radio members are very skilled and have special training in emergency communications, they are valuable asset. Beginning on the day of Sumatra Earthquake in December 2004, RAST [4] utilized the frequencies of 7.063 MHz, 7.070 MHz and 14.155 ± 10 MHz to support communications between government agencies, hospitals and the devastated communities along the coastline. RAST also reported the disaster situation to IARU members overseas via the HF link. For Tohoku Earthquake in March 2011, radio became the main source of information immediately following the tsunami that struck all major infrastructures in Japan. During JARL relief operation, the emergency traffic was kelp active in the frequencies of 3.525 MHz, 7.030 MHz, 7.043 MHz, 7.075 MHz, 14.100 MHz, 21.200 MHz and 28.200 MHz [5].

Taking frequencies into account, many low frequencies in the HF band were utilized during emergency operation. Those frequencies are normally affected from day-to-day bottom structure variation of the Earth ionosphere, where is influenced by both space weather activity and upper atmosphere. To ensure reliable use of HF radio, ionospheric effect on radio propagation should be investigated. HF-START is developed to fully understand the ionospheric effect and to provide necessary information to the users. Because providing radio propagation information must be reliable, the field campaign is launched to evaluate the HF-START.

SDR allows users to control its operating parameters those are involved in waveforms and signal processing by software. A digital receiver, LASER (Low-cost Amateur receiver System Employing RTL-SDR), has been developed based on RTL-SDR (https://www.rtl-sdr.com) that is cheap open-source hardware, and GNU Radio (http://gnuradio.org/) that is open-source software toolkit. GNU radio was employed on other open-source hardware to developed VHF-UHF receiver [6, 7], and HF receiver [8]. Vachhani and Rao [9] reported the implementing wideband FM receiver using RTL-SDR with GNU Radio. Development of HF receiver for ionospheric research by using RTL-SDR has never been reported. This paper proposes a development of low cost HF receiver system, namely LASER, for HF-START field campaign. The LASER's hardware and software description and an example of its successful HF measurement are reported.

2. Methodology

2.1 Development of HF prototype receiver

The open-source software toolkit for the SDR, GNU Radio, is utilized to program the basic function of the receiver. The software is written in Python and compatible with LINUX and Raspbian platform. The RTL-DSR [10], which is a very cheap SDR that uses a DVB-T TV tuner dongle based on the RTL2832U chipset, is used as a frontend to acquire the HF signals. The employed RTL-SDR is embedded with thermally compensated crystal oscillator (TCXO) with the worst-case specifications around 1 part per million (ppm). It means the stability is better than, for example, 5 Hz at 5 MHz and 10 Hz at 10 MHz. Because the RTL-SDR is originally designed for receiving the frequency range of around 64 MHz to 1700 MHz with a gap around 1100 MHz to 1250 MHz, the upconverter is used in this work to allow the developed system to receive the HF frequencies.

Figure 1 illustrates the block diagram of the LASER. The ApexRadio LS300A loop antenna is utilized. The cheap preamp, HiLetgo 0.1 MHz – 2000 MHz RF wideband amplifier 30 dB high gain low noise amplifier, is used to amplify the signal received from the loop antenna. The signal is passed through the RF switch, Mini-Circuit RSW-2-25P, which acts as a gate. This gate is controlled by the 1 pulse per second (1PPS) signal, which is generated from the Raspberry Pi 2 Model B, hereafter called as RasPi2. The 1PPS signal includes 0.1-sec off and 0.9-sec on signals. Because the RasPi2 has no internal clock, the clock in the RasPi2 is sync with GPS signal via a small GPS module of which its users' code is GYSFDMAXB. The GPS receiver with 1PPS allows locking of the local oscillators of the each RasPi2 at different stations on the GPS signal. Thus the time at all stations is synchronized. Hence, the arrival time of the signal can be accurately estimated. Once the HF signal passes the gate, it is mixed with the 100-MHz upconverter. At this point, the signal frequency becomes 100+f MHz, where f is the target HF frequency, which can be received by the RTL-SDR. The signal received by the RTL-SDR is logged to the RasPi2. Figure 2 shows the LASER after assembly.

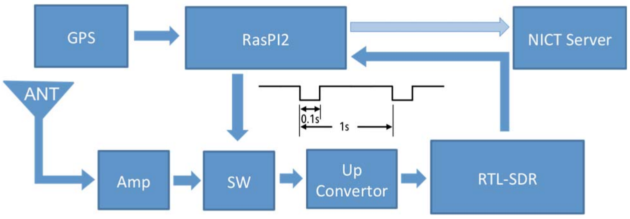


Figure 1. Block diagram for LASAR (Low-cost Amateur receiver System Employing RTL-SDR).

Operating parameters are set by the Python code. The signal flow graphs can be graphically seen as shown in Figure 3 by launching the GNU Radio Companion (GRC). During the operation, GUI (Graphic User Interface) is not necessary. Therefore the GNU radio blocks with the name heading with QT GUI are set to be off. The targeted frequencies can be set remotely. The RasPi2 records the received signal in binary format as shown in the 'File Sink' block. Crontab is employed to set the receiver to receive the signal at every 15 minutes following the domestic ionosonde observation schedule in Japan. The signal is then automatically recorded, logged into RasPi2 and an external hard disk, and transferred to the data server at National Institute of Information and Communications Technology (NICT) in Tokyo, Japan.

2.2 Field campaign design

The HF-START field campaign is designed to deploy 4 campaign-based HF receiver stations in Japan to allows analyzing the effect of the ionosphere on radio transmission, including the observation of the different propagation modes and the diurnal propagation channel variations. The campaign includes one Tx station at Nagara by Radio NIKKEI and four Rx stations at Wakkanai, Kokubunji, Yamagawa, and Okinawa as illustrated in Figure 4. The experiment is performed soon after the domestic ionosonde observation schedule in Japan at every 15 minutes. This allows observing the daily variations effect of the ionosphere on the measurements. Currently, receiving frequencies are set to be 3.925 MHz, 6.005 MHz and 9.595 MHz based on transmitting frequencies of Radio NIKKEI channel 1.

At the Tx, the signal is amplified and fed to horizontal dipole antennas radiating towards the northeast and the southwest direction. The received signal sequence at the Rx is expected to correlate to the original sequence. The waveform obtained from different Rx stations will be compared to estimate the real propagation distance. Propagation distance can be estimated by the time lag information that is retrieved from waveform comparison between two Rx stations, which are receiving the same signal. Single hop propagation via ionospheric reflection is initially assumed. Ionospheric data from NICT ionosonde [11] that is located near the reflection latitude and longitude will be deployed to measure ionospheric virtual height parameters (h'E and h'F), which correspond to the reflection height of a signal with the same group

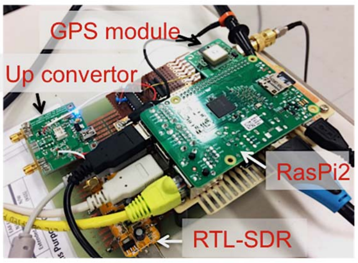


Figure 2. LASER after assembly.

delay. This allows retrieving a precise description of the local ionospheric profile, which is important for interpretation of the HF propagation distance.

2.3 Time lag estimation

Time lag information is retrieved by finding the maximum cross-correlation value of the two waveforms. Let *f(m)* is the waveform from Rx1 and *g(m)* is the waveform from Rx2, where *m* is digital bit. The cross-correlation of *f(m)* and *g(m)* can be estimated by

$$(f \oplus g)(n) = \sum_{m=-\infty}^{\infty} f^{*}(m)g(m+n) \qquad (1)$$

where f^* denotes the complex conjugate of *f*, *n* is the bit sliding displacement or lag. Positive *n* means that *g(m+n)* lags *f(m)*.

In one second, the waveform includes 16000 bits. If the cross-correlation is estimated by fully sliding the two waveforms, 31999 cross-correlation values per one-second data will be obtained. The maximum cross-correlation, which indicates the bit position where the two waveforms have the same or the most similar pattern, is referred as the bit lag that is equivalence to the time lag. The time lag is employed to convert to the different propagation distance between two Rx stations that is used to evaluate the radio propagation simulator.

2.4 HF-START

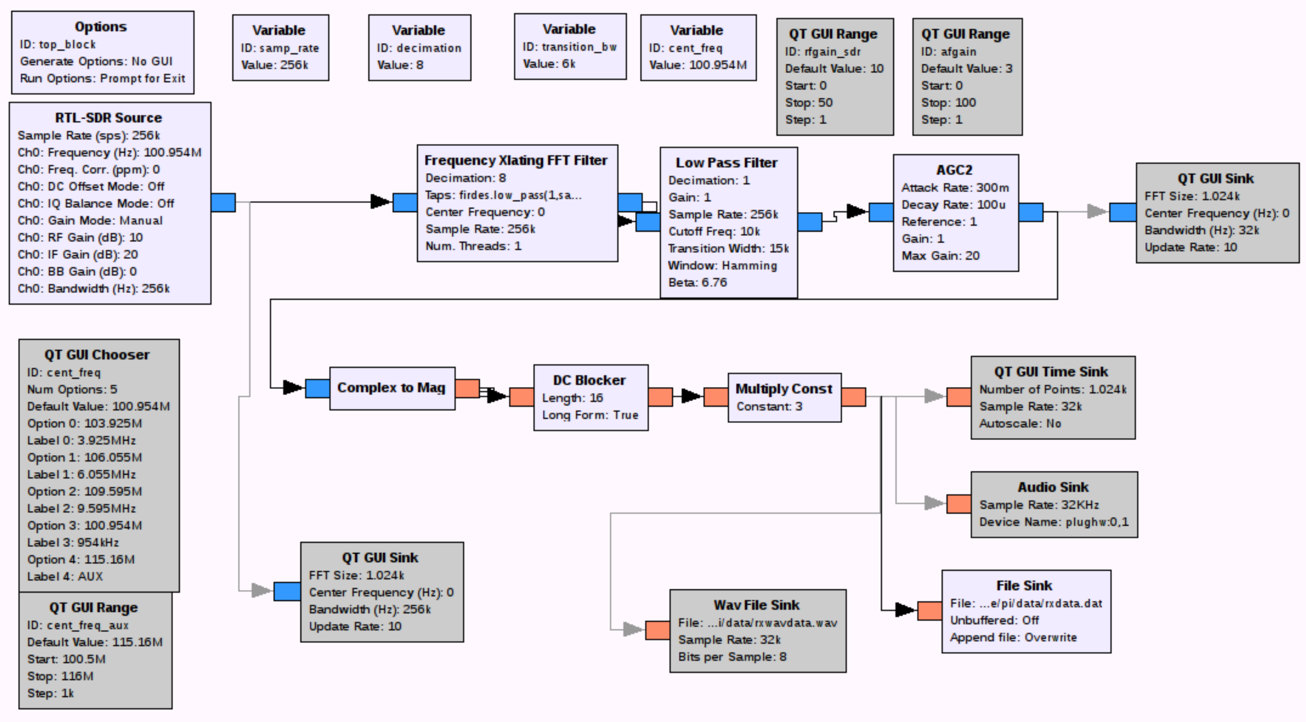
The radio propagation simulator, HF-START, is developed by employing the 3D ray tracing [12] for the targeted high frequency band. During the campaign, 3D ionosphere information from ionosonde-based 3D assimilation will be inputted into the HF-START as a propagation medium. Near realtime GNSS tomography [13] is optionally selectable. The propagation time and distance generated from the HF-START will be evaluated with those obtained from the aforementioned time lag technique.

3. Results

Figure 5 shows the 1-sec snapshot of the waveforms at assumed Rx1 (blue), assumed Rx2 (red), and white noise (black). Assumed Rx1 indicates the signal received from radio NIKKEI at the frequency of 6.055 MHz by the LASER at NICT in Kokubunji. Assumed Rx2 indicates artificial signal produced by modulation the 'Assumed Rx1' with a white noise, and shifting the signal forward for 500 bits. By employing Equation 1, the maximum cross-correlation is found correctly at -500 bit sliding that is equivalent to -31.25 millisecond. It is interpreted as the waveform at assumed Rx2 or *g(m)* leads the waveform at assumed Rx1 or *f(m)* for 31.25 millisecond. The playback of both waveforms is loud and clear.

4. Future plan

The current prototype, LASER, can be economically assembled as cheap as about 400 USD. Using a hand-made antenna will cut the cost to the half. It means the LASER is affordable even for developing countries in Southeast Asia. Therefore, the launch of similar campaign is planed to be in Southeast Asia via a collaborative research. Because the ionosphere as a propagation medium in Southeast Asia has different characteristic from that in Japan, interesting results are expected.



Options
ID: top_block
Generate Options: No GUI
Run Options: Prompt for Exit

Variable
ID: samp_rate
Value: 256k

Variable
ID: decimation
Value: 8

Variable
ID: transition_bw
Value: 6k

Variable
ID: cent_freq
Value: 100.954M

QT GUI Range
ID: rfgain_sdr
Default Value: 10
Start: 0
Stop: 50
Step: 1

QT GUI Range
ID: afgain
Default Value: 3
Start: 0
Stop: 100
Step: 1

RTL-SDR Source
Sample Rate (sps): 256k
Ch0: Frequency (Hz): 100.954M
Ch0: Freq. Corr. (ppm): 0
Ch0: DC Offset Mode: Off
Ch0: IQ Balance Mode: Off
Ch0: Gain Mode: Manual
Ch0: RF Gain (dB): 10
Ch0: IF Gain (dB): 20
Ch0: BB Gain (dB): 0
Ch0: Bandwidth (Hz): 256k

Frequency Xlating FFT Filter
Decimation: 8
Taps: firdes.low_pass(1,sa...
Center Frequency: 0
Sample Rate: 256k
Num. Threads: 1

Low Pass Filter
Decimation: 1
Gain: 1
Sample Rate: 256k
Cutoff Freq: 10k
Transition Width: 15k
Window: Hamming
Beta: 6.76

AGC2
Attack Rate: 300m
Decay Rate: 100u
Reference: 1
Gain: 1
Max Gain: 20

QT GUI Sink
FFT Size: 1.024k
Center Frequency (Hz): 0
Bandwidth (Hz): 32k
Update Rate: 10

QT GUI Chooser
ID: cent_freq
Num Options: 5
Default Value: 100.954M
Option 0: 103.925M
Label 0: 3.925MHz
Option 1: 106.055M
Label 1: 6.055MHz
Option 2: 109.595M
Label 2: 9.595MHz
Option 3: 100.954M
Label 3: 954kHz
Option 4: 115.16M
Label 4: AUX

QT GUI Range
ID: cent_freq_aux
Default Value: 115.16M
Start: 100.5M
Stop: 116M
Step: 1k

Complex to Mag

DC Blocker
Length: 16
Long Form: True

Multiply Const
Constant: 3

QT GUI Time Sink
Number of Points: 1.024k
Sample Rate: 32k
Autoscale: No

Audio Sink
Sample Rate: 32KHz
Device Name: plughw:0,1

QT GUI Sink
FFT Size: 1.024k
Center Frequency (Hz): 0
Bandwidth (Hz): 256k
Update Rate: 10

Wav File Sink
File: ...i/data/rxwavdata.wav
Sample Rate: 32k
Bits per Sample: 8

File Sink
File: ...e/pi/data/rxdata.dat
Unbuffered: Off
Append file: Overwrite

Figure 3. Signal flow graphs displayed by GNU Radio Companion (GRC).

5. Summary

The low cost HF receiver prototype named LASER is successfully developed for the HF-START evaluation campaign. It is remotely controllable via software. The signal received by the LASER has a good quality with loud and clear playback ability. Time lag is successfully retrieved from the cross-correlation technique. The LASER can be used to evaluate the HF-START as designed. The use of LASER will be expanded to Southeast Asia in the near future.

6. Acknowledgements

This work was partially supported by JSPS KAKENHI Grant Number JP15H05813, "The Project for Solar-Terrestrial Environment Prediction (PSTEP)", and NICT TRIAL fund.

7. References

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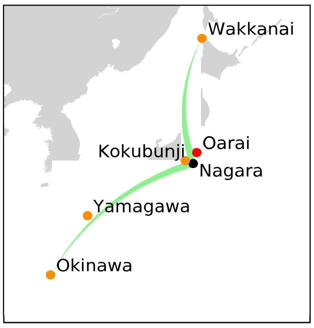

Figure 4. Location of Tx (black circle), planned Rx stations for the campaign (orange circle), NICT ionosonde stations (orange circle), and NICT HF direction finding observation (red circle). The light green strips show the possible radio path of each radio link.

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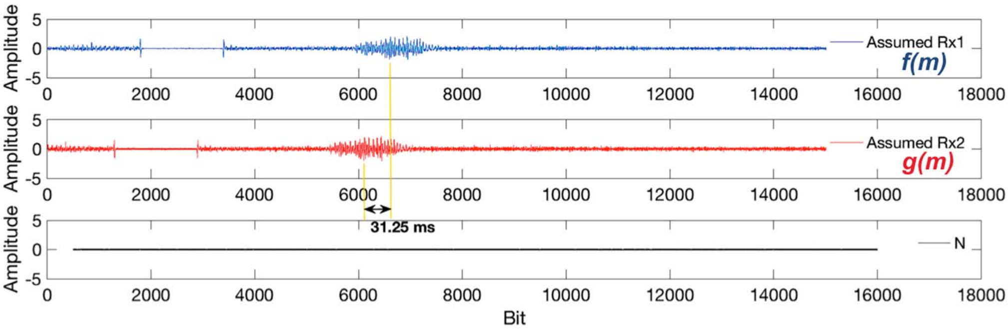

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