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Design of an SDR-Based ILS Receiver Tester for Performance Verification

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Abstract – *The ILS receiver must be tested to ensure its reliability. Commercial ILS receiver testers are prohibitively expensive. This study presents one of the first implementations of a functional portable ILS signal generator, utilizing a low-cost alternative with the HackRF One SDR and GNU Radio to generate precise ILS signals as input to the ILS receiver. The research features adjustable DDM/SDM parameters and a GUI interface. Testing with Thales 7010 showed maximum deviations of 0.0011 DDM (Localizer) and 0.0006 DDM (Glide Path), within operational tolerances. The GNU Radio block contains audio components to generate ILS DDM, including 90 Hz and 150 Hz, as well as processing blocks that prepare them for transmission via the HackRF One. Before evaluation, the research was calibrated with the ILS Analyzer Thales 7010. Testing with Thales 7010 showed maximum deviations of 0.0011 DDM (Localizer) and 0.0006 DDM (Glide Path), with SDM at ±40% (Localizer) and ±81% (Glide Path), within operational tolerances. As part of the verification, IFR-4000 was used to confirm the system's viability for receiver testing.*

Keywords – *Localizer; Glide Path; DDM; SDM; HackRF One.*

I. Introduction

THE Instrument Landing System (ILS) is a precision landing aid that provides both horizontal and vertical guidance as in [1–3]. Horizontal guidance utilizes the Localizer beacon signal, while vertical guidance relies on the Glide Path beacon signal. Guidance on the ILS can be formed by combining Carrier Sideband (CSB) and Sideband Only (SBO) components. In the Localizer, the RF SBO and CSB paths are 90 degrees out of phase, while the 90 Hz and 150 Hz audio signals on the SBO are 180 degrees out of phase [4, 5]. The operating frequency of the Localizer ranges from 108.1 to 111.95 MHz with a spacing of 200 kHz, whereas the Glide Path operates at a frequency between 329.3 and 335.0 MHz. Both the Localizer and Glide Path employ audio signals of 90 Hz and 150 Hz to determine the guidance points. The guidance point for the Localizer designates the runway centerline, while for the Glide Path, it indicates the appropriate landing angle (±3°). This reference point is denoted as DDM (Difference in Depth of Modulation) [6].

The modulation process in the air creates the formation of the upper sideband (USB) and lower sideband (LSB) relative to the carrier frequency. If the carrier frequency is F_c, then in the USB, there is modulation at $F_c + 90$ Hz and $F_c + 150$ Hz, while in the LSB, there is modulation at $F_c - 90$ Hz and $F_c - 150$ Hz. Depending on the direction of the aircraft's arrival, the right side of the runway will be dominated by 150 Hz audio, while the left side will be dominated by 90 Hz audio. The upper side of the landing angle will be dominated by 90 Hz audio, whereas the lower side will be dominated by 150 Hz audio [7]. The nominal Sum of the Modulation Depths (SDM) on the Localizer is 40%, while on the Glide Path, it is 80%.

Unlike ILS equipment used at airports, the ILS signal simulator is portable and not meant for aircraft use. This simulator is specifically designed to test receiving devices and is utilized on the ground for purposes such as aircraft avionics testing and ILS Analyzer instrument testing. From a cost perspective, using the ILS simulator is more affordable than utilizing actual ILS equipment for testing and measuring instruments. Thus, this research is crucial as it offers a solution for testing ILS receiver measuring instruments that are both cheaper and more efficient.

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By using GNU Radio, the modulation process on ILS can be simulated [8]. In addition to modulation, GNU Radio also performs filtering, channel coding, element synchronization, demodulation, and several other functions. These functions are packaged into blocks, and each block can be connected, determining how the data passes through them. GNU Radio processes only digital data, specifically complex baseband samples. To generate radio frequencies in an analog form that can be received by external devices, hardware capable of connecting with GNU Radio is required; one such device is the HackRF One. HackRF One is a hardware device that functions as both a transmitter and receiver of radio frequencies. The purpose of developing this device is to advance modern radio technology. Additionally, this device can be used to test other radio devices [9]. The HackRF One remains half-duplex, meaning that while it supports both receiving and transmitting functions for radio frequencies, it cannot operate simultaneously [10]. With Software Defined Radio (SDR) technology, this device operates from 1 MHz to 6 GHz. With this frequency range, the HackRF One can be used with 3G devices, Wi-Fi, FM, GPS, Radar (Mode-S), ADS-B, and aviation navigation equipment, including ILS.

Table 1: Previous research related to SDR-based transmitters

Research Authors	Research Focus
Reddy et al. (2020)	USRP N210 with GNU Radio
Ismail et al. (2022)	QAM and PSK modulation performance analysis over a narrowband HF channel
Arifin et al. (2022)	Performance measurement of SDR-based Automatic Identification System (AIS)
Kutsenko et al. (2023)	HackRF One-based ADS-B transmitter
This Research	ILS Simulator: SDR-Based ILS receiver device tester

The use of SDR technology has been extensively discussed in several prior studies, as illustrated in Table 1. Research by [11] shows the capability of GNU Radio to implement Amplitude Modulation (AM), which is the primary modulation type of the ILS. Research by [12] analyzes QAM and PSK modulation over the implementation of HackRF One with GNU Radio as transceiver, utilizing the Osmocom Sink in the flow graph. Another research by [13] compares the performance of the HackRF One and LimeSDR for radio frequency transmission, especially in Automatic Identification System (AIS) implementation. Moreover, research by [14] shows the capability of the HackRF One in the UHF (Ultra High Frequency) range for ADS-B transmitter, UHF is also the frequency range of the Glide Path.

Besides the primary literature about SDR, ILS signal forming has also been studied. Research by [15] explains how the electromagnetic interference affects the ILS signal. Research by [16] depicts the effect of the ES layer on the ILS signal. Research by [17] states how the DDM and SDM formed in the ILS Localizer and explains how the ILS receiver works.

Although several studies address the ILS and the SDR, no prior SDR implementation achieves FAA-grade ILS signal precision. This research validates a field-deployable SDR-based ILS simulator that meets ICAO Annex 10 requirements, utilizing the HackRF One device and GNU Radio for cost-effectiveness.

II. Research Methods

i. Research Specification

The research specifications will consider three main ILS parameters: DDM, SDM, and RF Level [18]. The output standards and tolerances refer to international documents where, for the Localizer, the nominal modulation for each audio at both 90 Hz and 150 Hz is 20%, with a guideline range of 18 to 22%. Meanwhile, for the Glide Path, the nominal modulation for each audio at both 90 Hz and 150 Hz is 40%, with a tolerance range of 37.5% to 42.5% [19]. The frequency limits provided in the research are based on the specifications of the NAV/COM IFR-4000 Test Set, specifically: Localizer frequencies of 108.1 MHz, 108.15 MHz, and 110.15 MHz; and Glide Path frequencies of 334.25 MHz, 334.55 MHz, and 334.7 MHz. The DDM adjustment limits of the research also refer to the DDM limits of the NAV/COM IFR-4000 Test Set. The DDM settings for the Localizer are 0, 0.093, 0.155, 0.200, −0.200, −0.093. The DDM settings for the Glide Path are: 0, 0.091, 0.175, 0.400, −0.400, −0.175, −0.091. RF Level also refers to the NAV/COM IFR-4000 Test Set configuration, set at −50 dBm for both the Localizer and Glide Path.

ii. Hardware and Software

HackRF One performs well with a channel bandwidth of less than 50 kHz [13]. Additionally, the HackRF One can transmit on the VHF band, which is the frequency band of Localizer, and the UHF (Ultra High Frequency) band [20] as the frequency range of the Glide Path. Therefore, HackRF One is regarded as an RF transmitter, while GNU Radio serves as the backend [14]. GNU Radio Version 3.9.2 is utilized, running on Python 3.9, with C# employed for the Graphical

User Interface (GUI).

The research software consists of two components: GNU Radio block software and user interaction software. The GUI software communicates with GNU Radio using the XML-RPC protocol. This interaction involves sending parameters from the GUI application to configure specific DDM, SDM, and RF levels, as well as relaying the status of the GNU Radio server back to the GUI application. Within GNU Radio, the Osmocom Sink is employed to connect with HackRF One hardware.

The GNU Radio block software includes two Signal Source blocks, one Add block, one Add Const block, one Float to Complex block, and one Osmocom Sink block. The signal source generates audio signals at 90 Hz and 150 Hz, which are the primary audio frequencies in the ILS. The Add Const adds a constant value to each of the mixed signals as the offset value. The Float to Complex block converts a single-sideband signal to a double-sideband signal. The Osmocom Sink block interfaces with the HackRF One device, allowing for adjustable Frequency and Gain. Figure 1 illustrates the GNU Radio block of the ILS Simulator.

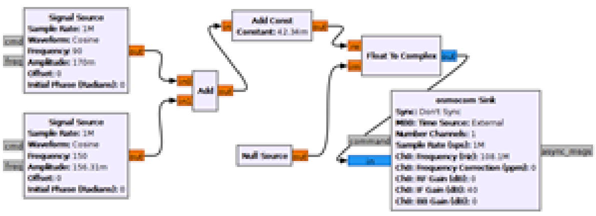


Figure 1: ILS Simulator GNU Radio block

The DDM, SDM, and RF level parameters can be obtained by combining the 90 Hz Amplitude parameter (`mod90`), the 150 Hz Amplitude parameter (`mod150`), and the Add Constant (`multi_1`) parameter. The GUI application sends these three parameters to GNU Radio using the XML-RPC protocol through port 8080, as shown in Figure 2 [21]. Selecting the DDM value in the GUI application will also change the combination of those parameters. Users can adjust the output frequency by modifying the `freq` parameter, which can be accessed through both the command-line interface and the graphical user interface (GUI) application.

The 90 Hz Amplitude, 150 Hz Amplitude, and Add constant parameter configuration, shown in Tables 2 (Localizer) and 3 (Glide Path), are obtained through several experiments in the calibration process. 108.1 MHz is used as the Localizer frequency reference, and 334.7 MHz is used for the Glide Path. Additionally, during the calibration process, the SDM should be maintained within the values of 40% (Localizer) and 80% (Glide Path) of each targeted DDM. The main

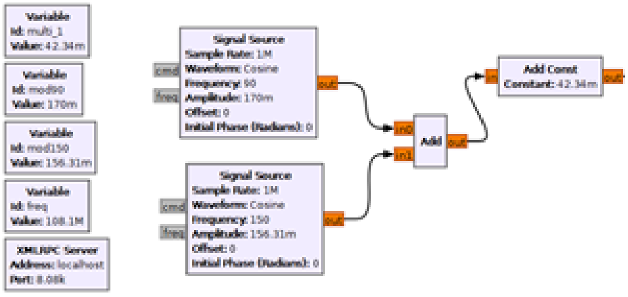


Figure 2: XML-RPC in ILS processing block

purpose of the calibration process is to obtain output based on the user input in the GUI.

iii. Test and Verification

The DDM, SDM, and RF level parameters will undergo deviation and change tests. The measuring instrument used for the deviation test is Thales 7010 ILS Analyzers. Meanwhile, the Verification Tool used is the NAV/COM Test Set IFR-4000.

The research testing involved connecting the radio frequency output from HackRF One to the ILS Analyzer via a 15 dB attenuator. The results were compared (verified) with the NAV/COM Test Set IFR-4000 output. Although the research employs radio frequencies, the testing uses cables as a directed medium to eliminate environmental and propagation influences on the test results. The block diagram for testing and verifying these results is shown in Figure 3.

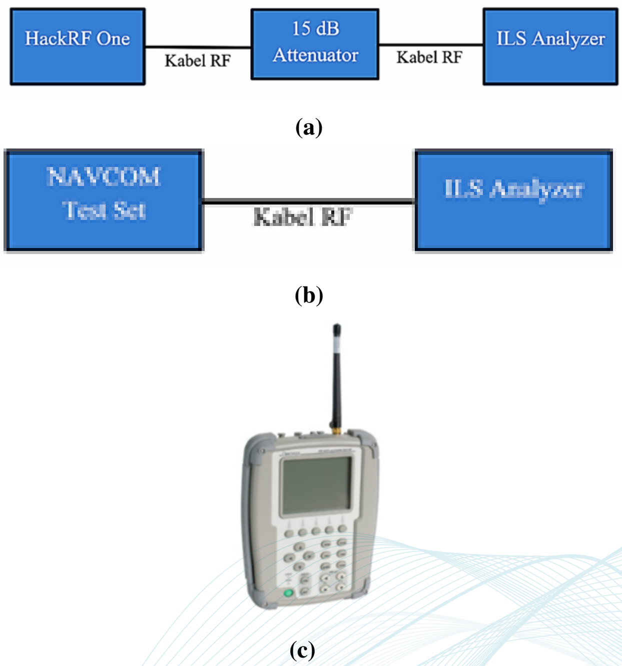
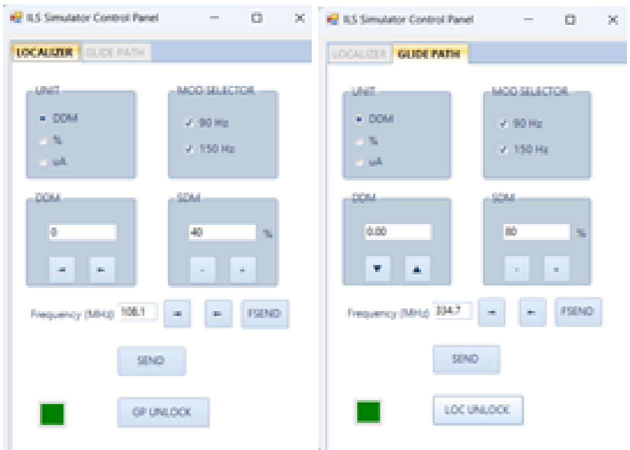


Figure 3: Configuration block: (a) Research testing, (b) Results verification, (c) NAV/COM Test Set IFR-4000

III. Results and Discussion

The GUI software features are Unit, DDM, Frequency, SDM, and MOD Selector menus. The Unit menu converts the units of the DDM settings. The DDM menu modifies the DDM value, while the Frequency menu sets the frequency as required. The GUI display is illustrated in Figure 4. The DDM unit can switch to other units to meet specific needs. Table 2 presents the DDM conversion results based on the DDM Unit displayed on the GUI for the Localizer, while Table 3 illustrates the Glide Path.



(a) (b)

Figure 4: GUI display of the ILS Simulator design (a) Localizer (b) Glide Path

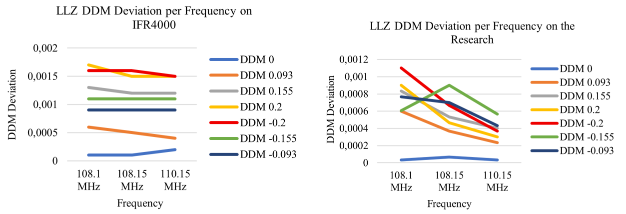
Table 2: Conversion of DDM Localizer to other units

DDM	% DDM	μA
0.000	0.0%	0
0.093	9.3%	90
0.155	15.5%	150
0.200	20.0%	193.55
-0.200	-20.0%	-193.55
-0.155	-15.5%	-150
-0.093	-9.3%	-90

Table 3: Conversion of DDM Glide Path to other units

DDM	% DDM	μA
0.000	0.0%	0
0.091	9.1%	78
0.175	17.5%	150
0.400	40.0%	342.86
-0.400	-40.0%	-342.86
-0.175	-17.5%	-150
-0.091	-9.1%	-78

The next test is conducted using the Thales ILS Analyzer. It was performed three times and then averaged for each selection of DDM values. Testing was also conducted on the research and the NAV/COM Test Set IFR-4000, and the results were then compared between the two devices. The DDM Localizer test is presented in Table 4, and the DDM Glide Path test is presented in Table 5.

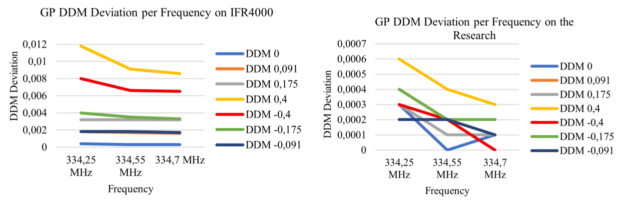


(a) (b)

Figure 5: Comparison of DDM deviation for each Localizer (LLZ) frequency (a) IFR-4000 (b) Research

Table 4: Average DDM values for each Localizer frequency

DDM	108.1 MHz		108.15 MHz		110.15 MHz	
	IFR-4000	Research	IFR-4000	Research	IFR-4000	Research
0.000	-0.00010	-0.000033	-0.00010	-0.000067	-0.00020	-0.000033
0.093	0.09360	0.093600	0.09350	0.093400	0.09340	0.093233
0.155	0.15630	0.155833	0.15620	0.155533	0.15620	0.155400
0.200	0.20170	0.200900	0.20150	0.200467	0.20150	0.200300
-0.200	-0.20160	-0.201100	-0.20160	-0.200667	-0.20150	-0.200367
-0.155	-0.15610	-0.155607	-0.15610	-0.155900	-0.15610	-0.155567
-0.093	-0.09390	-0.093767	-0.09390	-0.093700	-0.09390	-0.093433



(a) (b)

Figure 6: Comparison of DDM deviations at each Glide Path (GP) frequency (a) IFR-4000 (b) Research

Table 5: Average DDM values for each Glide Path frequency

DDM	334.25 MHz		334.55 MHz		334.70 MHz	
	IFR-4000	Research	IFR-4000	Research	IFR-4000	Research
0.000	-0.0004	-0.0003	-0.0003	0.0000	-0.0003	-0.0001
0.091	0.0928	0.0906	0.0927	0.0908	0.0926	0.0908
0.175	0.1782	0.1747	0.1782	0.1749	0.1782	0.1749
0.400	0.4118	0.4006	0.4091	0.4004	0.4086	0.4003
-0.400	-0.4080	-0.4003	-0.4066	-0.4002	-0.4065	-0.4000
-0.175	-0.1790	-0.1754	-0.1785	-0.1752	-0.1783	-0.1752
-0.091	-0.0928	-0.0912	-0.0928	-0.0912	-0.0927	-0.0911

Based on the standard deviation results, the research calibration produces quite good results, as the

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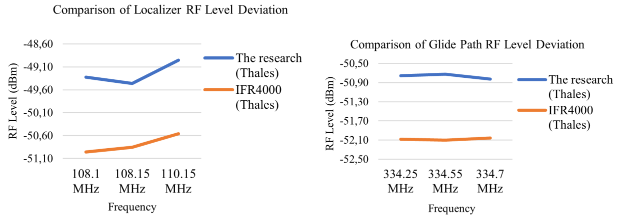

(a) **(b)**

Figure 7: Comparison of RF Level at each frequency in the research and IFR-4000 (a) Localizer RF Level comparison (b) Glide Path RF Level comparison

Table 6: Average SDM value for each Localizer frequency

Signal Source	108.1 MHz	108.15 MHz	110.15 MHz
IFR-4000	40.36	40.33	40.32
Research	40.44	40.27	40.18

values on the Thales measuring instrument match the calibration expectations, which were also obtained using the Thales instrument during the calibration process. Several factors influence these changes, including measurement uncertainty, the level of harmonic disturbances, and hardware stability. Two-tone intermodulation limits the SDR technology addressed by [11], which also affects the DDM of the research results. As suggested by prior research, an additional filter may be necessary to enhance HackRF One's performance. The research covers and limits only the stated frequencies of 108.1 MHz, 108.15 MHz, 110.15 MHz, 334.25 MHz, 334.55 MHz, and 334.7 MHz due to the calibration data sets working only for these frequencies.

The results of this study also expand the capabilities of SDR technology presented by [14] as an ILS signal simulator. Additionally, this research offers a practical and cost-effective way to evaluate ILS receivers without needing to buy a full commercial Navigation Tester suite solely for testing the ILS receiver.

IV. Conclusion

The research of the ILS signal simulator for the ILS receiver device tester, utilizing Software-Defined Radio and HackRF One, has been developed and tested. Testing was conducted at specific Localizer frequencies: 108.1 MHz, 108.15 MHz, and 110.15 MHz, along with Glide Path frequencies of 334.25 MHz, 334.55 MHz, and 334.7 MHz. At these frequencies, specific DDM values were set, and the results were measured using Thales ILS Analyzer. DDM for the Localizer included: 0, 0.093, 0.155, 0.200, -0.200, and -0.093. For the Glide Path, the values were: 0, 0.091, 0.175, 0.400, -0.400, -0.175, and -0.091. To verify the test results, the NAV/COM Test Set IFR-4000 was employed.

Table 7: Average SDM value for each Glide Path frequency

Signal Source	334.25 MHz	334.55 MHz	334.70 MHz
IFR-4000	81.79	81.63	81.59
Research	80.13	80.16	80.15

Table 8: Comparison of standard deviation in IFR-4000 and the research

Parameters	IFR-4000	Research
DDM Localizer	0.000268	0.000206
DDM Glide Path	0.001183	0.000190
SDM Localizer	0.01796%	0.10587%
SDM Glide Path	0.08531%	0.01184%
RF Level Localizer	0.16997 dBm	0.21299 dBm
RF Level Glide Path	0.01782 dBm	0.04206 dBm

The test results indicate that the research DDM exhibits 0.000062 lower deviation than IFR-4000 (Localizer) and 0.000993 lower deviation than IFR-4000 (Glide Path). However, the SDM and RF levels of IFR-4000 are favorable. Compared to prior research, this study unlocks more extensive usage of the SDR device and contributes to aviation safety by ensuring the performance of the ILS receiver device. With this research, an ILS receiver device can be tested without a complete navigation receiver test kit suite. Further research using more advanced hardware and a noise control device may yield improved results. Moreover, further research may include an antenna in device testing.

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