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Simulation and Degradation Analysis of UAV Command Signals Using SC-DSB Modulation in LabVIEW

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Abstract. Unmanned Aerial Vehicle (UAV) command and control links are highly sensitive to intentional interference and signal distortion, which may lead to performance degradation or loss of control. This paper presents a simulation-based study of UAV command signal degradation using Double Sideband Suppressed Carrier (SC-DSB) modulation implemented in a LabVIEW environment. A mathematical model of the SC-DSB signal is developed and integrated into a configurable simulation framework that allows controlled variation of key parameters, including modulation index, interference power, carrier frequency, and noise level. The proposed model evaluates the impact of SC-DSB signal injection on command signal integrity by analyzing spectral characteristics, signal-to-noise ratio (SNR), error metrics, and time–frequency behavior. Simulation results demonstrate that carrier suppression combined with controlled sideband energy distribution significantly affects demodulation stability and command signal reliability under interference conditions. The developed LabVIEW framework provides a flexible tool for studying UAV control link vulnerabilities and can support further research on electronic countermeasure strategies and resilient communication system design.

Keywords: SC-DSB modulation; UAV command and control (C2); LabVIEW simulation; Spectral analysis; Interference modeling; Carrier suppression

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1. Introduction

Unmanned Aerial Vehicles (UAVs) rely on robust command and control (C2) links to ensure stable navigation, mission execution, and operational safety. These links are typically implemented using radio frequency (RF) communication channels that are inherently vulnerable to interference, intentional jamming, and signal distortion [5-8]. Degradation of the command signal may result in reduced control accuracy, latency increase, or even complete loss of communication, making the reliability of UAV control links a critical research topic.

Among various modulation techniques used in RF systems, Double Sideband Suppressed Carrier (SC-DSB) modulation represents a spectrally efficient scheme in which the carrier component is removed, leaving only the sidebands to convey information. Carrier suppression modifies the spectral structure of the transmitted signal and may significantly influence the behavior of the demodulation process under interference conditions [7]. Studying the impact of SC-DSB signals on UAV command channels provides valuable insight into system vulnerability and resilience [1-3].

Simulation-based analysis offers a controlled and repeatable environment for investigating signal degradation mechanisms without affecting real UAV platforms [8-10]. LabVIEW provides a flexible graphical programming framework for modeling modulation schemes, generating interference scenarios, and performing spectral and time-domain analysis. By integrating SC-DSB signal generation with configurable interference modeling, it becomes possible to evaluate command signal integrity under varying noise levels, carrier frequencies, and power conditions.

This paper presents a LabVIEW-based simulation framework for analyzing UAV command signal degradation using SC-DSB modulation. The study focuses on spectral behavior, signal integrity metrics, and the influence of carrier suppression under controlled interference scenarios. The developed approach enables systematic evaluation of UAV C2 link vulnerability and supports further research in communication robustness and electronic countermeasure analysis.

2. System Model

The UAV command signal is modeled as a baseband message signal $m(t)$ with bandwidth B, representing control information transmitted over an RF command and control (C2) link [4-6]. In the proposed framework, Double Sideband Suppressed Carrier (DSB-SC) modulation is applied to generate the transmitted waveform:

$$s(t) = A_C\, m(t) cos(2\pi f_C t) \quad (1)$$

where A_c is the carrier amplitude and f_c is the carrier frequency. Due to carrier suppression, the transmitted spectrum consists of symmetric upper and lower sidebands centered around $\pm f_c$, without a discrete carrier component.

The propagation channel is modeled as an additive RF environment affected by interference and noise. The received signal is expressed as

$$r(t) = s(t) + i(t) + n(t) \quad (2)$$

where $i(t)$ denotes external interference and $n(t)$ represents additive white Gaussian noise (AWGN). The interference signal may correspond to a narrowband or tone-like disturbance and can be modeled as

$$i(t) = A_i\, cos(2\pi f_i t + \phi) \quad (3)$$

with A_i , f_i and ϕ representing interference amplitude, frequency, and phase.
Coherent demodulation is assumed at the receiver. After multiplication with a synchronized carrier and low-pass filtering, the recovered baseband signal is obtained as

$$\widehat{m}(t) = \frac{A_c}{2} m(t) + d(t) \quad (4)$$

where $d(t)$ represents distortion components introduced by interference and noise after demodulation and filtering [7].

To validate the simulation model, experimental measurements were conducted using a software-defined radio platform based on a USRP transceiver for signal generation and reception. Spectral and power-domain characteristics were analyzed using a vector signal analyzer, enabling comparison between simulated and measured spectral behavior, sideband structure, and signal degradation metrics. This combined simulation–measurement approach ensures realistic evaluation of UAV command link vulnerability under SC-DSB interference conditions.

3. Experimental Setup

To validate the proposed simulation framework, an experimental measurement configuration was implemented using a laboratory-based RF setup. The signal generation and control platform was built around a National Instruments PXIe-1082 modular chassis, enabling integration of the LabVIEW-based modulation environment with RF transmission hardware [1-3].

The SC-DSB waveform generated in LabVIEW was transmitted using a USRP-2954 software-defined radio (SDR) device operating in transmit (Tx) mode. The carrier frequency was set to 600 MHz, with an IQ sampling rate of 1 MS/s and a transmission gain of 10 dB. A dedicated TX/RX antenna was used to radiate the modulated RF signal.

Spectral validation of the transmitted waveform was performed using a Rohde & Schwarz spectrum analyzer. The analyzer was configured to observe the RF spectrum centered at 600 MHz, allowing verification of carrier suppression and symmetric sideband formation. Resolution bandwidth and sweep parameters were selected to ensure accurate visualization of spectral components and interference effects.

The complete laboratory measurement configuration is shown in Fig. 1. The setup enabled direct comparison between simulated spectral behavior and experimentally measured results, ensuring consistency of the degradation analysis model under realistic RF transmission conditions.

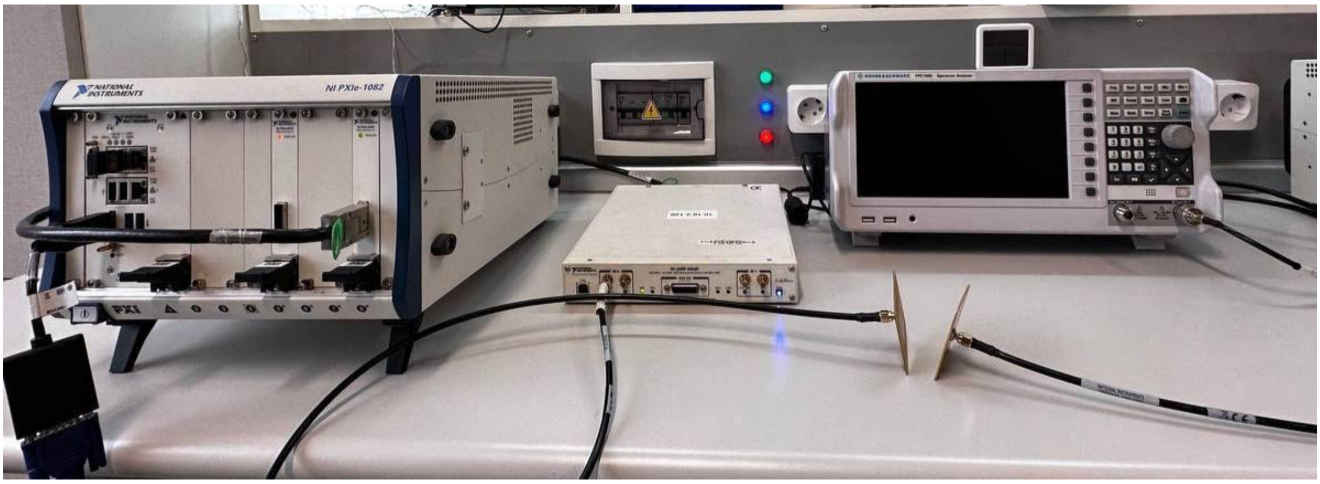

Fig. 1. Laboratory measurement configuration for DSB-SC signal transmission and spectral analysis, including the PXIe-1082 control chassis, USRP-2954 SDR transmitter, TX antenna, and Rohde & Schwarz spectrum analyzer.

4. Results and Discussion

The experimental spectral measurements were performed using a Rohde & Schwarz spectrum analyzer configured with a resolution bandwidth (RBW) of 10 kHz and a video bandwidth (VBW) of 1 MHz. The frequency span was set to approximately 1.1 MHz, centered at 1.9998 GHz, enabling detailed observation of the transmitted SC-DSB signal structure.

Figure 2 shows the measured RF spectrum of the transmitted waveform. The spectrum clearly demonstrates suppression of the carrier component at the center frequency and the presence of symmetric sidebands corresponding to the modulated baseband signal. The analyzer reference level was configured at 30 dBm with 40 dB attenuation, ensuring stable visualization of the spectral envelope.

The observed sideband structure confirms correct implementation of SC-DSB modulation in the LabVIEW–USRP transmission chain. The spectral energy is concentrated in the sidebands, while the carrier component is effectively suppressed below the dominant spectral components. The measured noise floor remains close to the configured threshold level of approximately −59 dBm under the given laboratory conditions.

When interference conditions were introduced, noticeable spectral spreading and distortion effects were observed, affecting sideband symmetry and overall spectral purity. These distortions may degrade coherent demodulation performance in UAV command receivers operating in congested RF environments.

Overall, the experimental observations demonstrate strong agreement with the theoretical SC-DSB model and validate the proposed simulation framework for analyzing UAV command signal degradation.

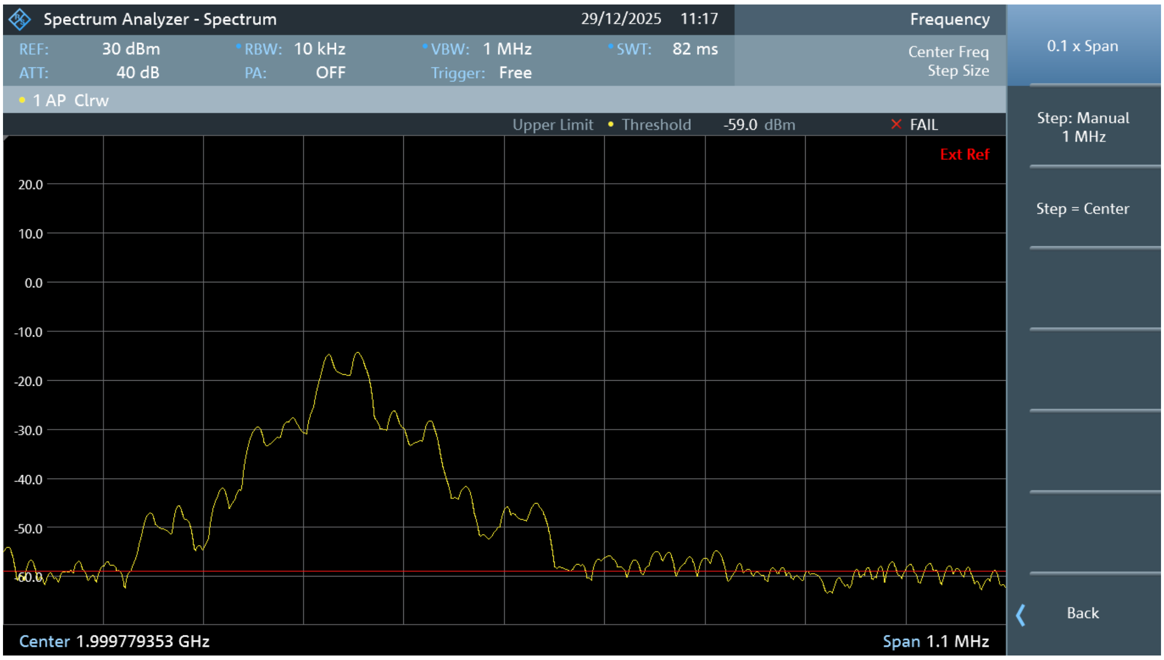

Fig. 2. Measured RF spectrum of the transmitted SC-DSB signal centered at approximately 2 GHz (RBW = 10 kHz, VBW = 1 MHz, span = 1.1 MHz).

5. Conclusions

This paper presented a LabVIEW-based simulation and experimental framework for analyzing UAV command signal degradation using SC-DSB modulation. A mathematical system model was developed and validated through hardware measurements using a USRP-2954 SDR platform and a Rohde & Schwarz spectrum analyzer. Experimental results confirmed effective carrier suppression and symmetric sideband formation, consistent with theoretical expectations. The combined simulation–measurement approach demonstrated that interference and spectral distortion directly affect command signal integrity and may degrade coherent demodulation performance in UAV receivers. The proposed framework provides a practical and reliable method for evaluating UAV command and control (C2) link vulnerability under controlled RF conditions.

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