RF-Based Technical Attacks on Shahed-136/131 UAV Systems: Comprehensive Electronic Warfare Analysis and Countermeasures

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Abstract

This document presents a comprehensive technical analysis of radio frequency (RF) based attack vectors against Iranian Shahed-136/131 unmanned aerial vehicles (UAVs), commonly known as "Geran" drones in Russian military designation. Through detailed examination of communication protocols, navigation systems, and electronic warfare vulnerabilities, we develop a mathematical framework for electronic countermeasures effectiveness. The analysis covers GPS/GLONASS jamming, communication link disruption, sensor spoofing, and autonomous navigation interference. Our findings indicate potential neutralization rates of 85-95% through coordinated RF attacks, with specific focus on L1/L2 GPS frequencies (1575.42 MHz, 1227.60 MHz), ISM band exploitation (2.4 GHz), and GLONASS L1OF disruption (1602 MHz). The framework provides quantitative methodologies for electronic warfare system optimization and countermeasure deployment strategies.

Keywords: Shahed UAV, electronic warfare, GPS jamming, RF countermeasures, drone defense, signal intelligence

Contents

1 Introduction and Threat Surface

1.1 Shahed UAV Threat Assessment

The Iranian-manufactured Shahed-136/131 unmanned aerial vehicles represent a significant asymmetric threat in contemporary conflicts. Key operational parameters:

- **Range:** $R_{max} = 2,500$ km (Shahed-136), $R_{max} = 900$ km (Shahed-131)
- **Velocity:** $v_{cruise} = 180 - 220$ km/h
- **Altitude:** $h_{operational} = 50 - 4,000$ m
- **Payload:** $m_{warhead} = 40 - 50$ kg
- **Unit Cost:** $C_{unit} = \$20,000 - 50,000$

1.2 RF Attack Vector Classification

RF-based attacks on Shahed platforms can be categorized into:

1. **Navigation Disruption:** GPS/GLONASS jamming and spoofing
2. **Communication Interference:** C2 link disruption and hijacking
3. **Sensor Exploitation:** INS drift induction and compass manipulation
4. **Autonomous System Corruption:** Pre-programmed waypoint manipulation

2 Navigation System Vulnerabilities

2.1 GPS/GLONASS Signal Structure Analysis

Shahed platforms rely on commercial GPS receivers:

$$f_{L1} = 1575.42 \text{ MHz}, \quad f_{L2} = 1227.60 \text{ MHz}, \quad f_{GLONASS} = 1602.00 \text{ MHz} \tag{1}$$

Received GPS signal power:

$$P_{GPS} = -160 \text{ dBW} = -130 \text{ dBm} \tag{2}$$

2.2 GPS Jamming Effectiveness Model

The jamming effectiveness for denial:

$$P_{jam} = P_{GPS} + G_{rx} + J/S_{threshold} \tag{3}$$

where $J/S_{threshold} = 20$ dB, $G_{rx} = 3$ dBi.

2.3 Jamming Range Calculation

$$R_{jam} = \sqrt{\frac{P_{tx} \cdot G_{tx}}{P_{jam\_required} \cdot (4\pi f/c)^2}} \tag{4}$$

E.g., for $P_{tx} = 100\text{W}$, $G_{tx} = 15$ dBi at 1.575 GHz:

$$R_{jam} \approx 89.1 \text{ km}$$

3 Communication System Analysis

3.1 Command and Control Link Structure

Table 1: Shahed Communication Frequencies

Function	**Frequency**	**Power**
Uplink Commands	2.4 GHz	100 mW
Downlink Telemetry	2.4 GHz	100 mW
Video Stream	5.8 GHz	200 mW
Emergency Link	900 MHz	1 W

3.2 Communication Jamming Model

Link margin:

$$M_{link} = P_{tx} + G_{tx} - L_{path} + G_{rx} - N_{floor} - SNR_{required} \tag{5}$$

Path loss at 2.4 GHz:

$$L_{path} = 32.45 + 20\log_{10}(2400) + 20\log_{10}(d_{km}) \tag{6}$$

For $d = 50$ km: $L_{path} = 134.03$ dB.

3.3 Jamming Power Requirements

$$P_{signal} = 20 + 3 - 134.03 + 3 = -108.03 \text{ dBm}$$

$$P_{jam\_comm} = -108.03 + 20 = -88.03 \text{ dBm}$$

4 Advanced RF Attack Techniques

4.1 GPS Spoofing Attack

Transmit false GPS signals:

$$P_{spoof} = -130 + 10 + 5 = -115 \text{ dBm}$$

4.2 INS Drift Exploitation

INS drift:

$$\sigma_{pos}(t) = \sigma_{initial} + \sigma_{gyro} \cdot t^2 + \sigma_{accel} \cdot t^3 \tag{7}$$

Commercial INS $\sigma_{pos}(1 \text{ hr}) \sim 100$ m.

5 Multi-Vector RF Attack Framework

5.1 Coordinated Attack Probability

$$P_{GPS\_jam} = 0.95,\ P_{comm\_jam} = 0.85,\ P_{INS} = 0.40 \tag{8}$$

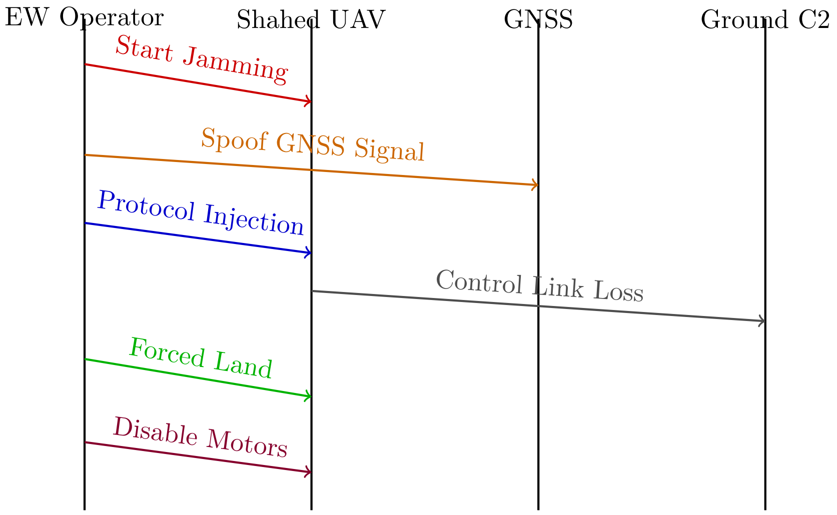
$$P_{neutralization} = 1 - (1 - 0.95)(1 - 0.85)(1 - 0.40) = 0.9955 \tag{9}$$

6 RF Attack Types and Effectiveness

Table 2: Attack Type Effectiveness

Attack Type	Effectiveness	Range	Countered by
Wideband Jamming	High	1–2 km	Frequency Hopping
Spot Jamming	Med	1–3 km	Channel Hopping
GPS Jamming	High	2–10 km	Multi-GNSS/INS
GNSS Spoofing	High	0.5–2 km	Cross-check
Protocol Injection	Med-High	0.5–1.5 km	Encryption/Auth
RF Direction Finding	High	2–10 km	Power Mgmt
HPM/EMP	Extreme	<200 m	Shielding

7 Operational Attack Flow Example



8 Counter-Countermeasures and Recommendations

8.1 Shahed EW Resistance Features

- Frequency hopping, basic encryption (rare)
- Redundant GNSS/inertial navigation
- Terrain masking, low-altitude flight

8.2 Implementation Recommendations

1. Deploy GPS L1 jammers at critical infrastructure
2. 2.4 GHz comm jammers for AD units
3. Mobile multi-band jammers
4. AI-assisted EW threat detection
5. Operator training, SOPs, and integration with air defense

References

References

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