**Z-ISR COTS Build  
Master Engineering Document**

*Locked Baseline • 2025-10-11*

# Document Control

|  |  |
| --- | --- |
| Title | Z-ISR COTS Build — Master Engineering Document |
| Version | 1.0 |
| Date | 2025-10-11 |
| Distribution | Internal / Engineering Use |

* This document consolidates the Z‑ISR COTS Build architecture, BOM, software, assembly, configuration, testing, and compliance into a single, engineer‑ready guide. It supersedes earlier drafts and spreadsheet notes.

# Table of Contents

[Document Control 1](#_Toc211105462)

[Table of Contents 2](#_Toc211105463)

[1. Executive Summary 3](#_Toc211105464)

[2. Configuration Snapshot (*Locked Baseline*) 3](#_Toc211105465)

[3. Bill of Materials 3](#_Toc211105466)

[3.1 Common Airframe (*All Drones*) 3](#_Toc211105467)

[3.2 Payloads by Role 4](#_Toc211105468)

[3.3 Apex/Toughbox Node 4](#_Toc211105469)

[4. Software Stack & Versions 4](#_Toc211105470)

[5. Mechanical & Electrical Assembly 5](#_Toc211105471)

[6. Flight Firmware & GCS Configuration 5](#_Toc211105472)

[7. Companion Computer Provisioning 5](#_Toc211105473)

[8. Apex/Toughbox Services 5](#_Toc211105474)

[8.1 MediaMTX Minimal Configuration (*Example*) 6](#_Toc211105475)

[8.2 Sidecar Transcode (*H.265 → H.264*) If Needed 6](#_Toc211105476)

[9. Metadata Schema, Transport & Overlays 6](#_Toc211105477)

[9.1 ZMeta JSON Schema (*Reference*) 6](#_Toc211105478)

[10. TAK/CoT Integration (*Baseline Output*) 6](#_Toc211105479)

[10.1 ZMeta → CoT Mapping 7](#_Toc211105480)

[10.2 CoT Examples 7](#_Toc211105481)

[11. Networking & Media 7](#_Toc211105482)

[12. Ground Tests & Acceptance 8](#_Toc211105483)

[13. Compliance & Security 8](#_Toc211105484)

[Appendix A — Docker Compose (*Apex Services*) 8](#_Toc211105485)

[Appendix B — mavlink-router (*Jetson*) 9](#_Toc211105486)

[Appendix C — Time Sync (*chrony/ptp4l*) 9](#_Toc211105487)

[Appendix D — Spare Parts & Field Kit 9](#_Toc211105488)

# 1. Executive Summary

This master document establishes a single, concrete Z‑ISR COTS baseline across seven drones (D‑01…D‑07) and one ground “Apex/Toughbox” node. It specifies the hardware (*airframe, powertrain, avionics, payloads*), software (*flight, companion, media, TAK*), network transports, metadata schema, and step‑by‑step build, test, and acceptance procedures. The baseline emphasizes COTS availability, reliability, and maintainability. KLV/STANAG‑4609 remains optional for FMV interop; JSON/ZMeta is authoritative internally, with CoT for TAK integration.

# 2. Configuration Snapshot (*Locked Baseline*)

**Airframe:** Holybro X500 V2

**Flight Controller:** Pixhawk 6C + PM06 (*analog*)

**GNSS/Timing:** Holybro H‑RTK F9P with PPS

**Powertrain:** Sunnysky X4108S 480KV • 40A 4‑in‑1 BLHeli\_S • 12×4.5 props • 6S 6000–8000mAh LiPo

**Telemetry:** SiK 915MHz (*US*) / 868MHz (*EU*)

**Companion (*on‑drone*):** Jetson Xavier NX (*8GB*), Ubuntu 20.04, JetPack 5.1.x, 1TB NVMe

**Roles:** D‑01 Boson 640 18mm; D‑02 Boson 640 24mm; D‑03 Airspy R2 (*omni*); D‑04 Airspy R2 (*DF*); D‑05 1× MEMS+Teensy; D‑06 6× MEMS+Teensy; D‑07 IMX477 EO

**Apex/Toughbox:** Jetson AGX Orin (*or Xavier*), VITEC encoder (*H.264/H.265*), MediaMTX, JSON→CoT gateway, fanless GbE switch, ≥30Ah LiFePO4 + 150W inverter

# 3. Bill of Materials

## 3.1 Common Airframe (*All Drones*)

|  |  |
| --- | --- |
| **Component** | **Specification** |
| Frame | Holybro X500 V2 |
| Flight Controller | Pixhawk 6C + PM06 (*analog*) |
| GNSS/Timing | H‑RTK F9P with PPS |
| Motors | Sunnysky X4108S 480KV |
| ESC | 40A 4‑in‑1 BLHeli\_S (*3–6S*) |
| Props | 12×4.5 fixed |
| Battery | 6S 6000–8000mAh LiPo |
| Telemetry | SiK 915/868MHz |
| Companion | Jetson Xavier NX (*8GB*) + 1TB NVMe |
| Mounts/Add‑ons | Isolation plates, ferrites, UBECs, fuses, harness kit |

## 3.2 Payloads by Role

|  |  |
| --- | --- |
| **Drone** | **Payload Specification** |
| D‑01 Thermal (*Narrow*) | FLIR Boson 640 18mm • Teledyne bridge • 5V/2A UBEC • fixed plate/gimbal |
| D‑02 Thermal (*Wide*) | FLIR Boson 640 24mm • Teledyne bridge • 5V/2A UBEC • fixed plate/gimbal |
| D‑03 RF Sweep | Airspy R2 • lightweight omni whip • shielded cabling |
| D‑04 RF DF | Airspy R2 • compact DF antenna set • rigid mast |
| D‑05 Acoustic TDoA | 1× MEMS (*SPH0645/INMP441*) • Teensy 4.1 • PPS |
| D‑06 Acoustic DOA | 6× MEMS array • Teensy 4.1 • PPS |
| D‑07 EO Anchor | IMX477 (*RPi/Arducam HQ*) • fixed plate or 2‑axis micro‑gimbal (*CSI‑2 to Jetson*) |

## 3.3 Apex/Toughbox Node

|  |  |
| --- | --- |
| **Component** | **Specification** |
| Compute | Jetson AGX Orin (*or Xavier*) |
| Encoder | VITEC Diamond‑class H.264/H.265 (*KLV optional*) |
| Media Router | MediaMTX (*SRT ↔ WebRTC/LL‑HLS/RTSP; rolling records*) |
| TAK Gateway | JSON→CoT service (*TLS to TAK Server*) |
| Network | Fanless 5‑port GbE switch |
| Storage | Removable SSD (≥*2TB*) |
| Power | ≥30Ah LiFePO4, 150W inverter, isolated 5V/12V rails |
| Enclosures | Pelican 1600 class • compute case + power/logistics case |

# 4. Software Stack & Versions

Pin versions during build and record them in the SBOM. The following stack is standardized across the fleet.

|  |  |
| --- | --- |
| Layer | Component |
| Flight & GCS | PX4 or ArduPilot (*stable*) • QGroundControl |
| Runtime | Docker + docker-compose |
| MAVLink Bridge | mavlink-router or MAVProxy/MAVROS |
| Video/Media | GStreamer + FFmpeg |
| Media Router | MediaMTX |
| TAK Integration | JSON→CoT Gateway |
| Thermal | FLIR Boson SDK + OpenCV |
| RF | SoapySDR + airspy/hackrf tools (*Linux*) |
| Acoustic | Teensy tools + Python FFT/DOA |
| AI/Fusion | NumPy + PyTorch + FastAPI |
| Monitoring | Prometheus + Grafana |
| Time Sync | PPS (*primary*), chrony/ptp4l (*LAN backstop*) |

Locked Software Baseline

# 5. Mechanical & Electrical Assembly

• Assemble the Holybro X500 V2 frame; mount battery tray; route XT60 main leads.

• Install Pixhawk 6C on an isolation plate; connect PM06 (*analog*).

• Mount 4‑in‑1 ESC; wire X4108S motors; leave props OFF for bench tests.

• Mount H‑RTK F9P on mast; route PPS to Jetson and to Teensy (*for acoustic roles*).

• Install SiK telemetry radio; ensure antenna clear from GNSS and carbon structures.

• Mount Jetson Xavier NX, fan, and NVMe; route CSI‑2 (*EO*) and USB (*Boson/RF/Teensy*).

• Secure payload mounts per role; add ferrites and shielding on RF lines; strain‑relieve harnesses.

# 6. Flight Firmware & GCS Configuration

• Connect to QGroundControl; flash PX4 (*or ArduPilot*) stable.

• Run full calibrations: accelerometer, compass, radio, level, ESC.

• Run QGC Motor Test to verify direction; check frame orientation.

• Set failsafes (*RC loss, low battery*) and verify GPS lock.

• Confirm MAVLink stream rates and telemetry to companion computer.

# 7. Companion Computer Provisioning

• Flash Jetson Xavier NX with JetPack 5.1.x (*Ubuntu 20.04*).

• Install Docker and docker‑compose; create per‑role containers.

• Install mavlink‑router or MAVProxy/MAVROS for telemetry distribution.

• Enable PPS GPIO handling; configure chrony/ptp4l as LAN backstop for time sync.

• Deploy role services (*thermal/RF/acoustic/EO*) and validate logs/health.

# 8. Apex/Toughbox Services

Start MediaMTX to ingest SRT from the encoder and restream to WebRTC/LL‑HLS/RTSP. Run the JSON→CoT gateway to publish CoT events to TAK Server over TLS. Monitor with Prometheus/Grafana and record video segments to SSD for chain‑of‑custody.

## 8.1 MediaMTX Minimal Configuration (*Example*)

webrtcAdditionalHosts: [ "10.0.0.10" ]  
hls: yes  
hlsVariant: lowLatency  
  
paths:  
 eo\_overlay:  
 record: yes  
 recordFormat: mpegts  
 recordSegmentDuration: 1h

## 8.2 Sidecar Transcode (*H.265 → H.264*) If Needed

paths:  
 eo\_overlay: {}  
 eo\_overlay\_h264:  
 runOnReady: >  
 ffmpeg -i rtsp://127.0.0.1:8554/eo\_overlay  
 -c:v libx264 -preset veryfast -pix\_fmt yuv420p -b:v 3M  
 -f rtsp rtsp://127.0.0.1:8554/eo\_overlay\_h264  
 runOnReadyRestart: yes

# 9. Metadata Schema, Transport & Overlays

Drones publish JSON (*ZMeta*) at 5–10 Hz: timestamp, drone\_id, modality, location{lat,lon,alt}, confidence, bounding\_box, summary. Apex fuses within a 300–500 ms buffer and ±250 ms window, draws overlays (*bbox, DOA arrows, RF pulses*) and emits the annotated video via SRT. KLV/STANAG‑4609 is optional for FMV interop; CoT is used for TAK integration.

## 9.1 ZMeta JSON Schema (*Reference*)

{  
 "timestamp": "2025-10-11T18:22:04Z",  
 "drone\_id": "D-03",  
 "modality": "rf",  
 "location": { "lat": 34.123456, "lon": -117.123456, "alt": 472.0 },  
 "confidence": 0.78,  
 "bounding\_box": [412,120,560,300],  
 "summary": "RF burst @ 915.5MHz; SNR 22dB"  
}

# 10. TAK/CoT Integration (*Baseline Output*)

A lightweight gateway subscribes to ZMeta and translates each message to a CoT <event>, sent to TAK Server via TLS (*TAK v1 stream*).

## 10.1 ZMeta → CoT Mapping

|  |  |  |
| --- | --- | --- |
| ZMeta Field | CoT Field(*s*) | Notes |
| timestamp (*UTC*) | time, start | Use same value for both |
| timestamp + TTL | stale | 10–60 s typical |
| drone\_id | uid; detail/contact@callsign | Unique ID and callsign |
| modality | type | Use refpoint (b-m-p) or SPI (b-m-p-s-p-i) |
| location.lat/lon/alt | point@lat/lon/hae (+ce/le) | Include error if available |
| summary | detail/remarks | Short free-text |
| confidence | detail/\_\_confidence@value | Custom extension field |

## 10.2 CoT Examples

<event version="2.0" uid="ZISR-D03-2025-10-11T18:22:04Z"  
 type="b-m-p" how="m-g"  
 time="2025-10-11T18:22:04Z" start="2025-10-11T18:22:04Z" stale="2025-10-11T18:22:34Z">  
 <point lat="34.123456" lon="-117.123456" hae="472.0" ce="15.0" le="15.0"/>  
 <detail>  
 <contact callsign="D-03"/>  
 <remarks>RF burst @ 915.5MHz; SNR 22dB</remarks>  
 <\_\_modality value="rf"/>  
 <\_\_confidence value="0.78"/>  
 </detail>  
</event>

<event version="2.0" uid="ZISR-D01-SPI-2025-10-11T18:22:08Z"  
 type="b-m-p-s-p-i" how="m-g"  
 time="2025-10-11T18:22:08Z" start="2025-10-11T18:22:08Z" stale="2025-10-11T18:22:38Z">  
 <point lat="34.123789" lon="-117.123012" hae="466.2" ce="12.0" le="12.0"/>  
 <detail>  
 <contact callsign="D-01"/>  
 <remarks>Thermal hotspot; bbox=[412,120,560,300]</remarks>  
 <\_\_modality value="thermal"/>  
 <\_\_confidence value="0.86"/>  
 </detail>  
</event>

# 11. Networking & Media

• Telemetry: SiK (*915/868 MHz*) to GCS; optional IP bridge.

• Metadata: UDP multicast (*low latency*); optional MQTT/TCP for reliable C2.

• Video: SRT from encoder → MediaMTX → WebRTC/LL‑HLS/RTSP to viewers.

• Bandwidth: Metadata ~2–5 KB/s per drone; Video 2–4 Mb/s at 720p30 with overlays.

# 12. Ground Tests & Acceptance

Use this checklist to declare each aircraft and the Apex ready. Mark each item on paper or electronically.

☐ **Bench** (*props OFF*): sensors power on; Jetson temps nominal; MAVLink telemetry visible; ZMeta heartbeat at 5–10 Hz.

☐ QGC calibrations complete; Motor Test OK; frame orientation correct; failsafes verified.

☐ **Hover**: stabilize/position hold; current draw acceptable; no RF/GNSS interference with SDR running.

☐ **Payload checks**: Thermal image/NUC; RF sweep sanity; acoustic DOA vectors stable; EO exposure correct.

☐ **Apex end‑to‑end**: overlays render; SRT 720p30 at 2–4 Mb/s; CoT received by TAK; logs written to SSD.

# 13. Compliance & Security

• Airspace: Operate under applicable rules; Remote ID as required; maintain VLOS unless authorized.

• RF: Passive reception only within permitted bands; respect local law.

• Audio: Follow consent rules where applicable during testing.

• Supply Chain: Track SBOM (*SPDX*) at build; avoid restricted components; secure OTA/credentials.

# Appendix A — Docker Compose (*Apex Services*)

version: "3.8"  
services:  
 mediamtx:  
 image: bluenviron/mediamtx:latest  
 network\_mode: host  
 volumes:  
 - ./mediamtx.yml:/mediamtx.yml:ro  
 - /data/recordings:/recordings  
 environment:  
 - MTX\_PATHS\_EO\_OVERLAY\_RECORD=yes  
  
 cot-gateway:  
 image: ghcr.io/yourorg/zmeta-cot-gateway:latest  
 network\_mode: host  
 volumes:  
 - ./cot-config.yml:/config.yml:ro  
 restart: unless-stopped  
  
 prometheus:  
 image: prom/prometheus:latest  
 network\_mode: host  
 volumes:  
 - ./prometheus.yml:/etc/prometheus/prometheus.yml:ro  
  
 grafana:  
 image: grafana/grafana:latest  
 ports: [ "3000:3000" ]  
 volumes:  
 - ./grafana:/var/lib/grafana

# Appendix B — mavlink-router (*Jetson*)

[General]  
TcpServerPort=5760  
ReportStats=true  
  
[UartEndpoint serial0]  
Device=/dev/ttyTHS1  
Baud=921600  
  
[UdpEndpoint ground]  
Mode=Server  
Address=0.0.0.0  
Port=14550  
  
[UdpEndpoint services]  
Mode=Server  
Address=0.0.0.0  
Port=14551

# Appendix C — Time Sync (*chrony/ptp4l*)

# /etc/chrony/chrony.conf (Jetson)  
refclock PPS /dev/pps0 refid PPS lock NMEA  
server 127.127.28.0 prefer # GPSD SHM if used  
allow 10.0.0.0/8  
makestep 1.0 3

# ptp4l example  
ptp4l -i eth0 -m -S -2

# Appendix D — Spare Parts & Field Kit

• Propellers (*12×4.5*) — 4 full sets

• ESC 40A 4‑in‑1 — 1 spare per 3 drones

• UBECs (*5V/12V*) — 2 each

• Ferrites, heat‑shrink, JST/servo leads

• Landing gear, standoffs, screws assortment

• SiK radio spares and antennas

• Batteries (*6S 6–8Ah*) — 2 per airframe