

Master Specification: Vertical Field Anchor (VFA) V1.21

Role: Field-Level Relay, "Truth" Node, & Routing Coordinator | **Network Density:** 1 VFA per Field (Aggregating LRZs deployed at 1 per 15 Acres)

As the primary field-level relay and intelligence hub of the FarmSense SFD (single field deployment) architecture, the Vertical Field Anchor (VFA) operates as a high-fidelity subsurface data logger, a secure routing node, and the critical baseline calibration tool—the absolute "Truth" node—for the Zo Scientist Engine.

Network Topology: There is exactly **one VFA deployed per field** (typically at the pivot center or a highly representative baseline zone). This single VFA is responsible for intercepting the 128-bit encrypted FHSS chirps from the surrounding high-density Lateral Root-Zone (LRZ) scouts, which are deployed at a strict density of **1 unit per 15 acres**.

Instead of treating each data point in isolation, the solitary VFA seamlessly aggregates this expansive lateral spatial data, combines it with its own 48-inch deep-profile vertical readings, and securely routes the highly compressed, unified payload to the central Farm Hub located at the pivot. By serving as the localized edge coordinator, the VFA ensures that absolutely no data is lost during cellular blackouts. More importantly, it establishes the rigorous empirical ground-truth required for ultra-precision irrigation, yield optimization, and the strict legal water-use auditing demanded by local water authorities.

The Seasonal Deployment Model: To maximize the lifespan of the high-value electronics, the VFA utilizes a two-phase seasonal deployment strategy. The outer structural shells act as ultra-cheap, geo-located permanent docking stations that remain buried in the field year-round. The internal, highly sensitive sensor sleds are dropped into these shells *after* spring planting and physically extracted just prior to harvest. This workflow entirely eliminates the risk of deep-freeze winter battery degradation while perfectly preserving the exact spatial baseline required by the Zo Server's Kriging algorithms.

1. Structural Housing & Climate Control (The Seasonal Docking Station)

The VFA housing has been radically re-engineered using a dual-cylinder architecture designed to completely isolate external structural loads from the delicate internal electronics.

- **The Outer Shell (The Docking Station):** Constructed from **Standard 2" Schedule 40 UV-Stabilized HDPE** (which provides an exact Inside Diameter of 2.067" / 52.5mm). By utilizing an exact 4-foot (48-inch) cut, the outer 2" pipe sits completely flush with the soil surface. This shell stays in the ground over the winter. HDPE maintains its molecular ductility in extreme sub-zero soil temperatures, meaning it will not shatter when the ground freezes. If

damaged by deep tillage during the off-season, the shell is treated as a disposable consumable and easily replaced.

- **Elevated Mast & Antenna Array:** Because the 2" shell is flush-mounted, the removable C&C Cap (attached to the internal sled) utilizes a **1" Pultruded Fiberglass Mast** to elevate the antenna base 3 feet above the soil. This radio-transparent mast is topped with a 3-foot SS-304 stainless steel whip antenna featuring a heavy-duty spring base. This gives the VFA the RF clearance it needs to transmit over mature crop canopies while safely deflecting tractor booms and pivot tires.
- **Monolithic Chemical Fix (HDPE-to-HDPE):** The outer shell is paired with a **Custom HDPE Tapered Driving Tip**. The tip is chemically fused directly to the shell using a specialized, automated application of low-surface-energy Structural HDPE Acrylic Epoxy. This homogenous bond ensures the permanent shell remains water-tight and intact against frost-heave separation throughout the winter months.
- **The Removable Internal Sled:** The core internal structure is a **48-Inch 50mm Co-Extruded Alpha-Sled** capped with precision **Injection-Molded Circular End-Caps**. This sled acts as a robust internal spine, clamping the 48U sequence of modular cartridges into a perfectly rigid stack. This entire sled is a removable payload, extracted prior to harvest to overwinter safely indoors.
- **The Seasonal Climate (+5 psi Defense):** Upon seasonal insertion, Viton (FKM) 2" O-rings seal the sled against the shell walls. The internal cavity is flushed and pressurized to **+5 psi with Dry Nitrogen**, creating an inert, zero-humidity environment that acts as an active defense against micro-fractures and groundwater ingress.

2. Custom Relay Logic & Encryption (The Hub Pipeline)

By stripping the VFA down to pure routing and encryption functions, we have intentionally offloaded all heavy cellular backhaul requirements and complex Zo Worksheet computations to the central Farm Hub.

- **Interference Mitigation & FHSS:** The VFA utilizes a highly sensitive onboard FHSS mesh receiver to intercept the transmit-only "dumb" chirps from its designated fleet of 15-acre LRZs. By scattering these micro-transmissions across 75 different frequencies, the statistical probability of a packet collision is effectively zero.
- **Edge Decryption & Aggregation:** As the VFA catches these asynchronous chirps, it performs localized Edge Decryption, aggregating the raw electrical counts from the 15-acre lateral nodes with its own high-fidelity deep-soil data.
- **AES-256 Security Architecture:** To ensure absolute security, the aggregated payload is immediately re-encrypted using military-grade AES-256 protocols before leaving the VFA.

- **Local 900MHz Uplink:** The VFA utilizes a local high-gain 900MHz LoRa uplink to bounce the secure payload directly to the District Farm Hub, bypassing the need for an expensive cellular modem.

3. The "Proxy Method" Sensor Array (48-Inch / 48U Sequence)

To preserve the absolute integrity of the +5 psi nitrogen seal, the VFA employs advanced non-contact sensing, shooting high-frequency dielectric fields directly *through* the removable 50mm sled wall, across the nitrogen gap, and straight through the permanent HDPE shell.

Locked 48U Physical Stack Sequence & Strategic Agronomic Depth Logic:

- **Slot 1:** 1U Bulk Stamped Desiccant Pack (*Acts as the apex trap for any growing-season moisture*)
- **Slots 2-5:** 4U Battery #1 (*Contains three 21700 lithium-ion cells in a space-saving triangular cluster. Powers polyimide heating films during unpredictable spring/fall frosts*)
- **Slots 6-9:** 4U Extruded Spacer
- **Slot 10:** 1U Advanced Sensor (*10" Depth: Active root zone proxy for NPK/pH/VWC/EC/Temp*)
- **Slots 11-14:** 4U Battery #2 (*Triangular 3-cell cluster*)
- **Slots 15-17:** 3U Extruded Spacer
- **Slot 18:** 1U Basic Sensor (*18" Depth: Standard evaporation transition monitoring*)
- **Slots 19-24:** 6U Extruded Spacer
- **Slot 25:** 1U Advanced Sensor (*25" Depth: The "Pivot Point" for mature root zone moisture management*)
- **Slots 26-29:** 4U Battery #3 (*Triangular 3-cell cluster*)
- **Slots 30-34:** 5U Extruded Spacer
- **Slot 35:** 1U Basic Sensor (*35" Depth: Tracks the descending wetting front during active irrigation cycles*)
- **Slots 36-39:** 4U Battery #4 (*Triangular 3-cell cluster*)
- **Slots 40-43:** 4U Extruded Spacer
- **Slots 44-47:** 4U Battery #5 (*Triangular 3-cell cluster*)
- **Slot 48:** 1U Advanced Sensor (*48" Depth: The Deep Percolation Anchor. Identifies water/nitrogen that have escaped the root zone entirely for legal Water Court defensibility*)

4. The Seasonal Deployment Workflow & OEM BOM

The Post-Planting "Blitz" & Harvest Extraction: 1. **Post-Planting Insertion:** Crews locate the permanent in-ground 48-inch HDPE shells. The pre-calibrated sensor sled is dropped into the

shell, locked, pressurized with nitrogen, and the RF-handshake is verified in under 15 minutes. 2.

Harvest Extraction: Just prior to the potato/barley harvest, crews pull the C&C caps, extract the internal sensor sleds entirely for warehouse trickle-charging, and cap the permanent ground shells with cheap blanking plugs for the winter.

Hyper-Granular OEM Scale BOM (1,280 Unit Tier): This ledger deconstructs the hardware costs to the bare-metal component level. It incorporates maximum-tier OEM direct-fabrication pricing (bulk extrusion, automated PCBA, bulk cell sourcing) and the triangular battery cell configuration to validate a highly optimized, enterprise-scale unit cost of exactly **\$159.65**.

Category	Component Detail & Sub-Assembly Breakdown	Supplier / Scale Method	Unit Cost	Ext. Cost
Housing	2" SCH 40 UV-HDPE (4ft Cut - Flush Mount)	Direct Extruder (Bulk Spool)	\$4.00	\$4.00
Housing	Custom HDPE Tapered Driving Tip (Mold-V5)	Proprietary (High-Cavity Mold)	\$4.25	\$4.25
Housing	1" Pultruded Fiberglass Mast (3.5ft Cut)	Industrial Pultrusion Bulk	\$3.50	\$3.50
Antenna	3ft SS-304 Whip + Spring Base	OEM Direct Fab (Bulk)	\$4.50	\$4.50
Adhesive	Structural HDPE Acrylic Epoxy	Automated Bulk Dispensing	\$0.85	\$0.85
Seals	Viton (FKM) 2" O-Rings (2 units @ \$0.40/ea)	OEM Rubber Fab (Bulk)	\$0.80	\$0.80
Computing	Custom VFA Relay & AES-256 Encryption PCB	Tier-1 PCBA (Pick & Place)	\$6.50	\$6.50
Climate	1U Stamped Silica Desiccant Matrix	Bulk Supply	\$1.50	\$1.50
Structure	48-Inch 50mm Co-Extruded Alpha-Sled Chassis	Continuous Extrusion	\$3.25	\$3.25
Structure	Injection-Molded Circular Sled End-Caps (Top & Bottom)	High-Cavity Mold	\$0.60	\$0.60
Structure	Extruded HDPE Multi-U Spacers (22U Volume)	Recycled Bulk	\$0.15	\$0.15

Power (x5)	4U Battery Cartridge:	Direct Cell Sourcing	\$16.75/ea	*\$83.75*
 - 21700 Li-Ion Cells (3 per cart triangular): *\$10.50*				
Adv. Sensor (x3)	1U Advanced Sensor (Value Engineered):	Fab-Direct Assembly	\$14.00/ea	*\$42.00*
 - FDR Capacitance-to-Digital IC: \$6.00				
Basic Sensor (x2)	1U Basic Sensor (Value Engineered):	Fab-Direct Assembly	\$2.00/ea	\$4.00
 - PCB-Etched Planar EC Coils: \$2.50				
 - ARM Cortex-M0+ & RS485: \$2.50				
 - Polyurethane Potting/Housing: \$3.00				
TOTAL	Per Unit Hardware Cost <small>(All units OEM Scale)</small>		\$159.65	