FLASH – Field-deployable Lightning Analysis System using High-speed RF

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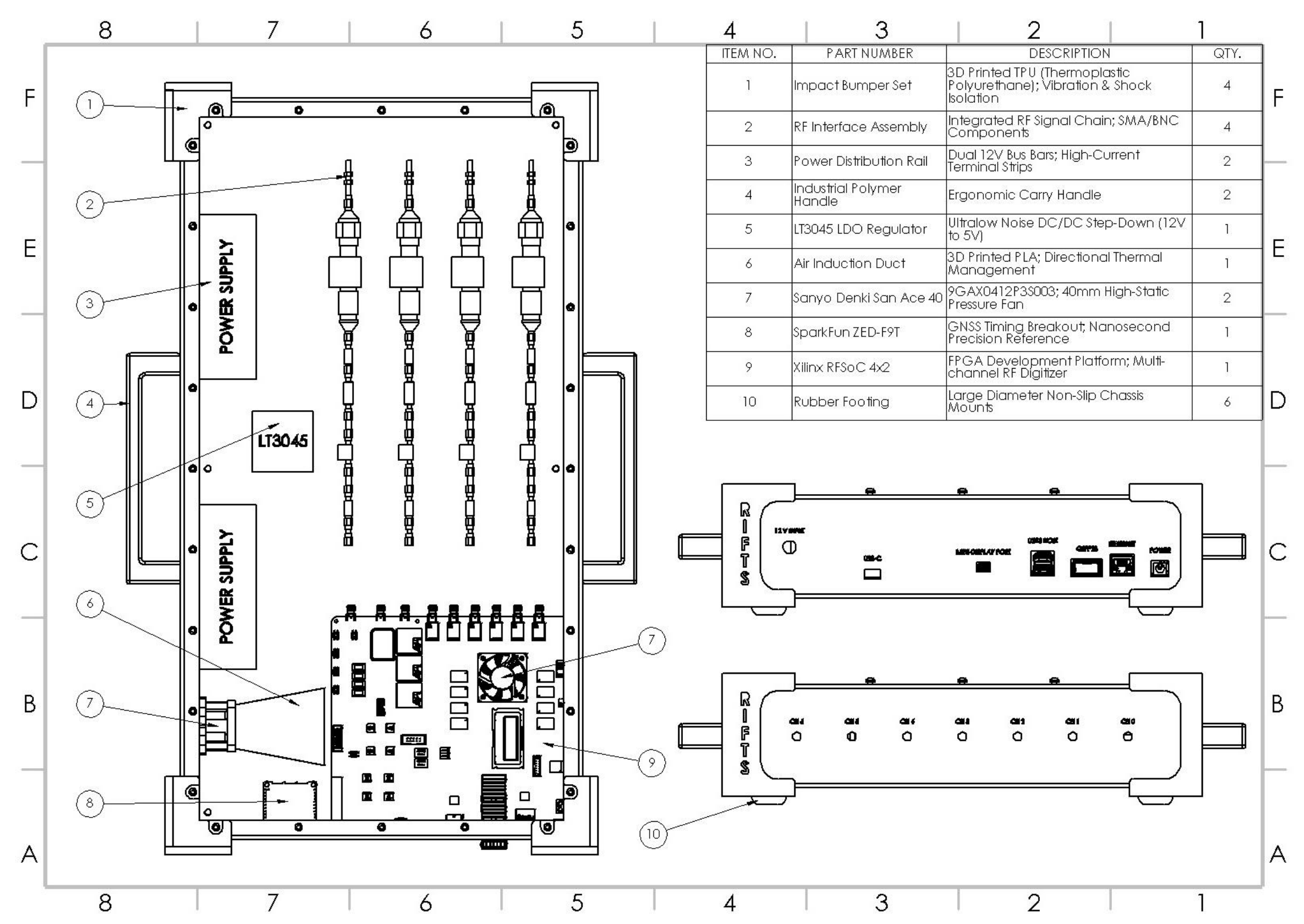
Background & Motivation

- **Environmental Limitations:** Cloud cover and storm dynamics limit **lightning** studies; RF (radio frequency) detection enables all-weather, pre-flash measurements but **requires EMI (electromagnetic interference) shielding** for sensitive electronics.
- **Portability & Integration Gap:** RF systems are bulky; Reliable & ready acquisition favors a mobile platform with EMI shielding and **weatherproof site hardware.**

Design Objectives

- **RF Integrity:** Engineer an RF-tight enclosure for the RFSoC (Radio Frequency System-on-Chip) 4x2 platform **to minimize signal noise** during high-energy events, while **precisely modeling cutouts for manufacturing to accommodate the board's specific ports**—balancing tight tolerances with EMI shielding to mitigate leakage at interface boundaries.
- **Environmental Resilience:** Develop an **IP67-rated** OmniLOG® antenna mount capable of sustained field deployment in severe weather.
- **Rapid Deployment:** Design a portable, modular system to transition from stationary labs to **mobile** research locales.

Ruggedized RFSoC 4x2 Field Enclosure



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Impact Bumper Set	3D Printed TPU (Thermoplastic Polyurethane); Vibration & Shock Isolation	4
2	RF Interface Assembly	Integrated RF Signal Chain; SMA/BNC Components	4
3	Power Distribution Rail	Dual 12V Bus Bars; High-Current Terminal Strips	2
4	Industrial Polymer Handle	Ergonomic Carry Handle	2
5	LT3045 LDO Regulator	Ultralow Noise DC/DC Step-Down (12V to 5V)	1
6	Air Induction Duct	3D Printed PLA; Directional Thermal Management	1
7	Sanyo Denki San Ace 40	9GAX0412P3S003; 40mm High-Static Pressure Fan	2
8	SparkFun ZED-F9T	GNSS Timing Breakout; Nanosecond Precision Reference	1
9	Xilinx RFSoC 4x2	FPGA Development Platform; Multi-channel RF Digitizer	1
10	Rubber Footing	Large Diameter Non-Slip Chassis Mounts	6

Figure [1]: Ruggedized FLASH Enclosure Assembly. An integrated field instrument featuring precision GNSS timing and custom 3D-printed thermal and impact protection for lightning research.

Figure [2]: High Quality Render. Isometric FLASH enclosure.

- **Shielding & Construction:** Fabricated from **0.064" 5052 Aluminum** with **continuous seam welds** and high-density screw spacing to eliminate seam-antenna effects (see Figure [5]) and maximize EMI attenuation.
- **Thermal Architecture:** Replaced stock cooling with **dual 19.1 – 80.4 CFM (cubic feet per minute) fans** and **3D-printed air ducts**, ensuring laminar flow across the RFSoC's processing cores during high-duty cycles.
- **Mechanical Resilience:** Integrated **3D-printed TPU (thermoplastic polyurethane) corner pads** and ergonomic handles for vibration isolation and rapid deployment in varied terrain.

Shielding Theory

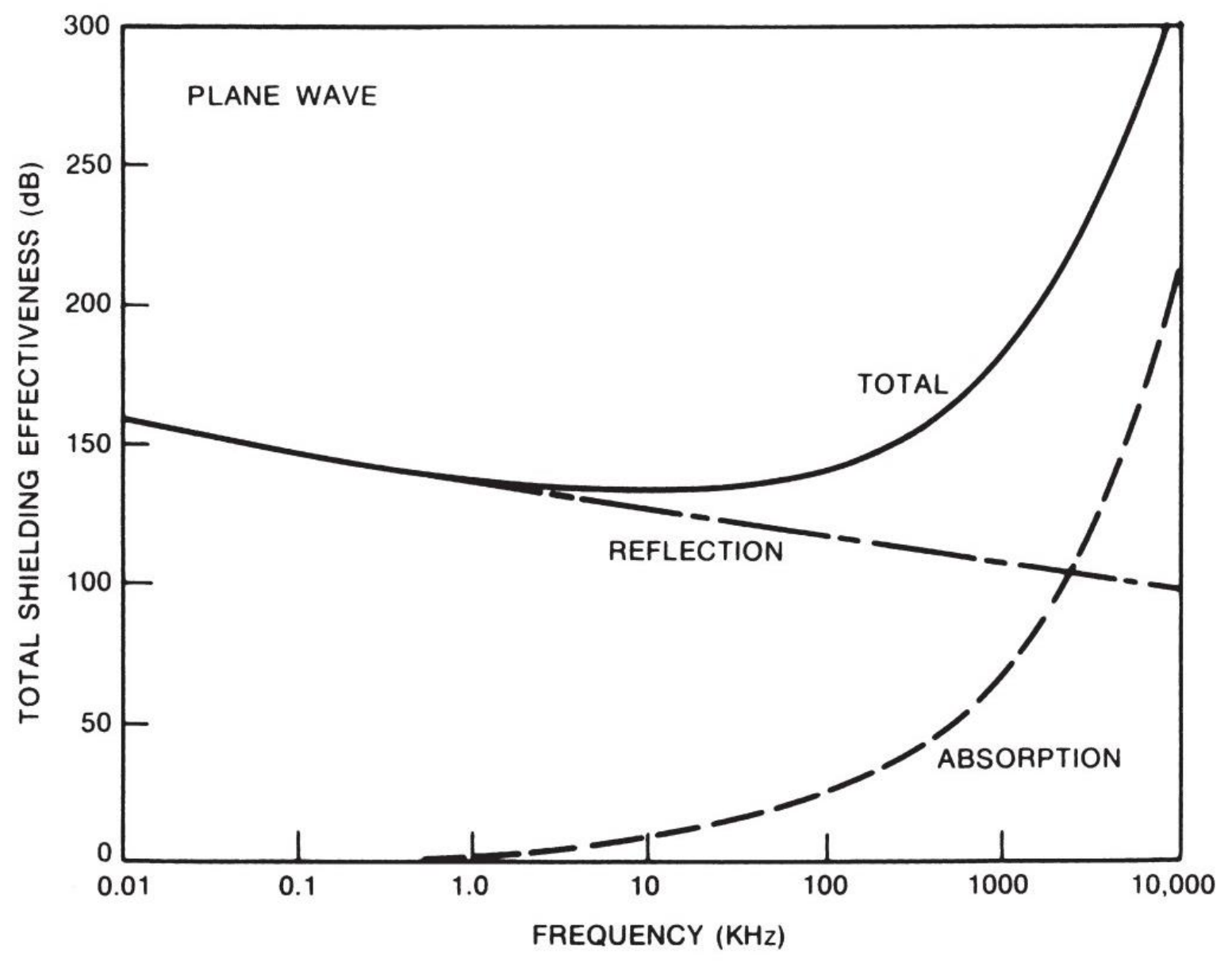


Figure [3]: Total Shielding Effectiveness vs. Frequency. Far-field shielding effectiveness of 0.02-in copper [1].

- **SE = A + R**: Shielding effectiveness is the sum of absorption and reflection; thickness > skin depth = attenuation [1].
- **Aperture Theory:** Shielding is affected by the ratio of wavelength (λ) to gap size (L). Attenuation is maximized when $L \ll \lambda$ preventing apertures from acting as slot-antennas [1].

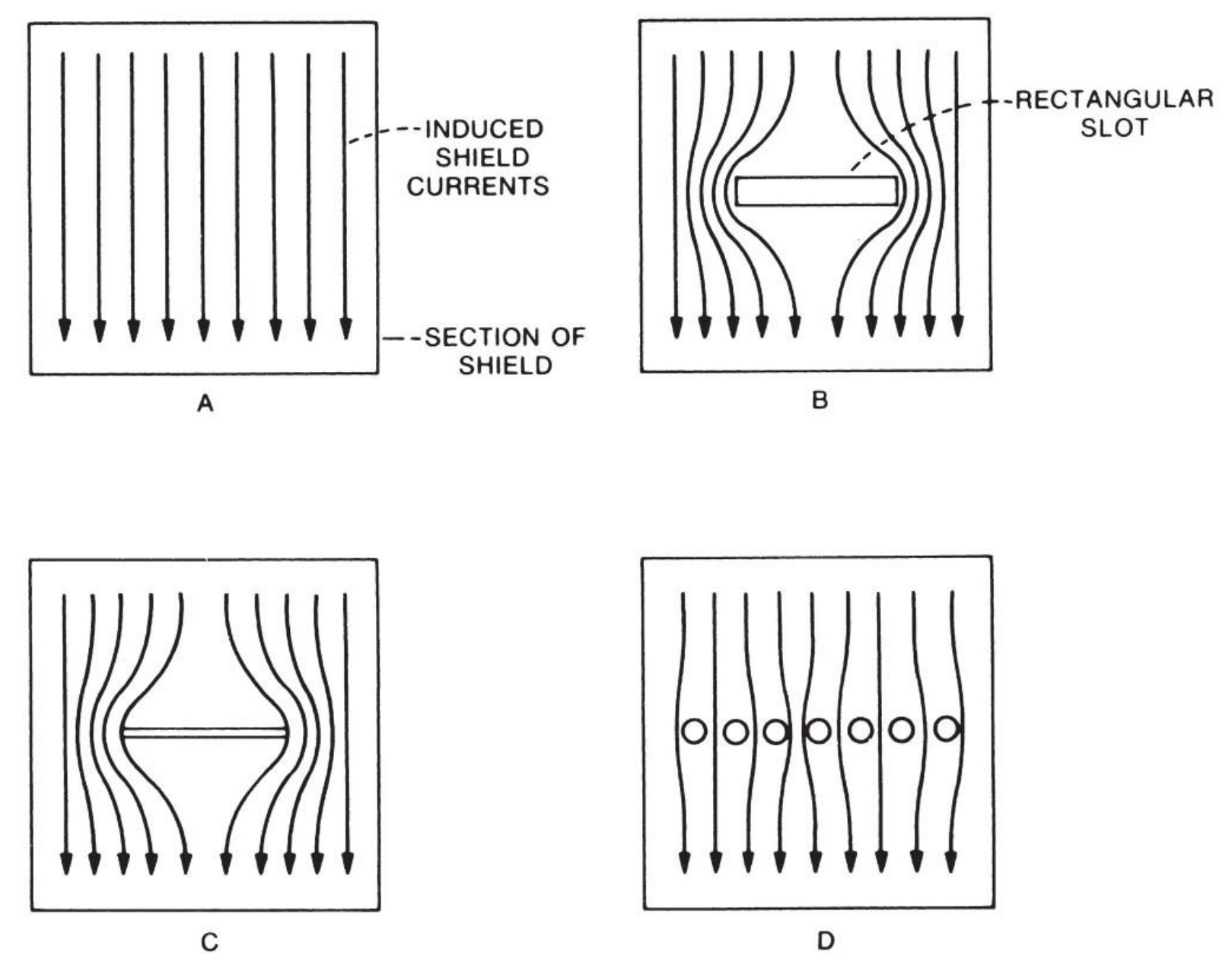


Figure [4]: Circuit Theory Approach. Effect of shield discontinuities on induced current distributions [1].

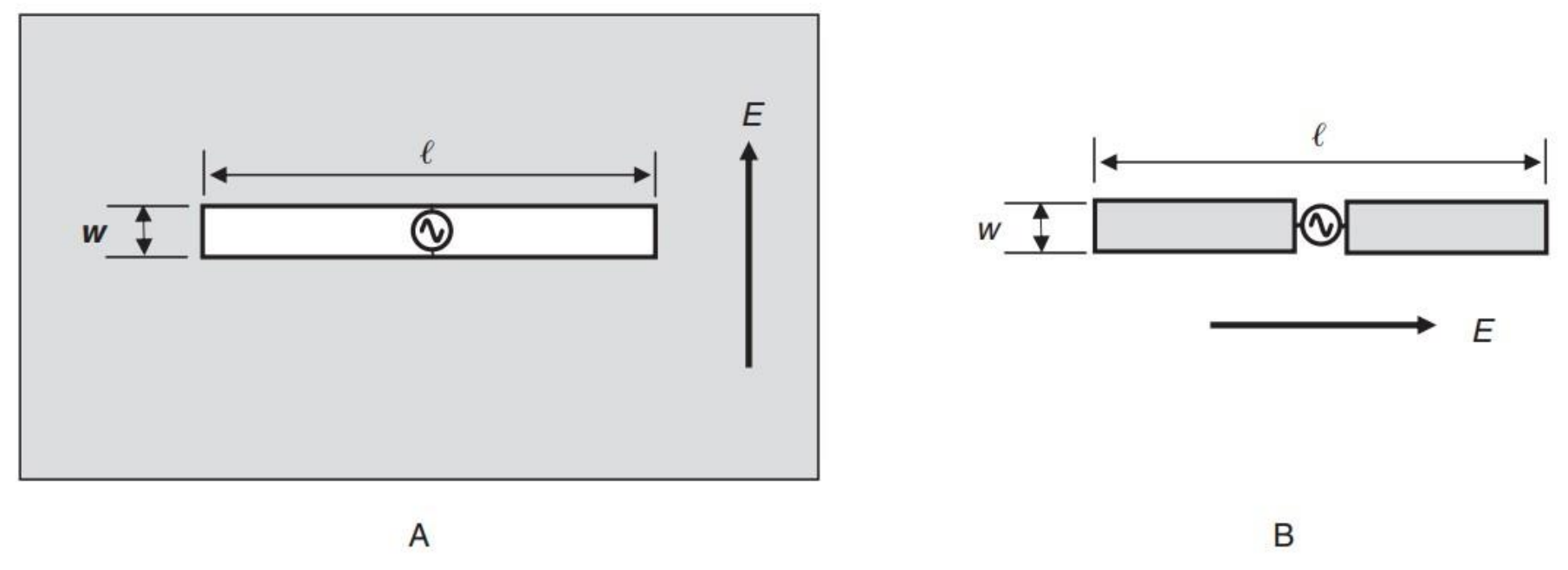
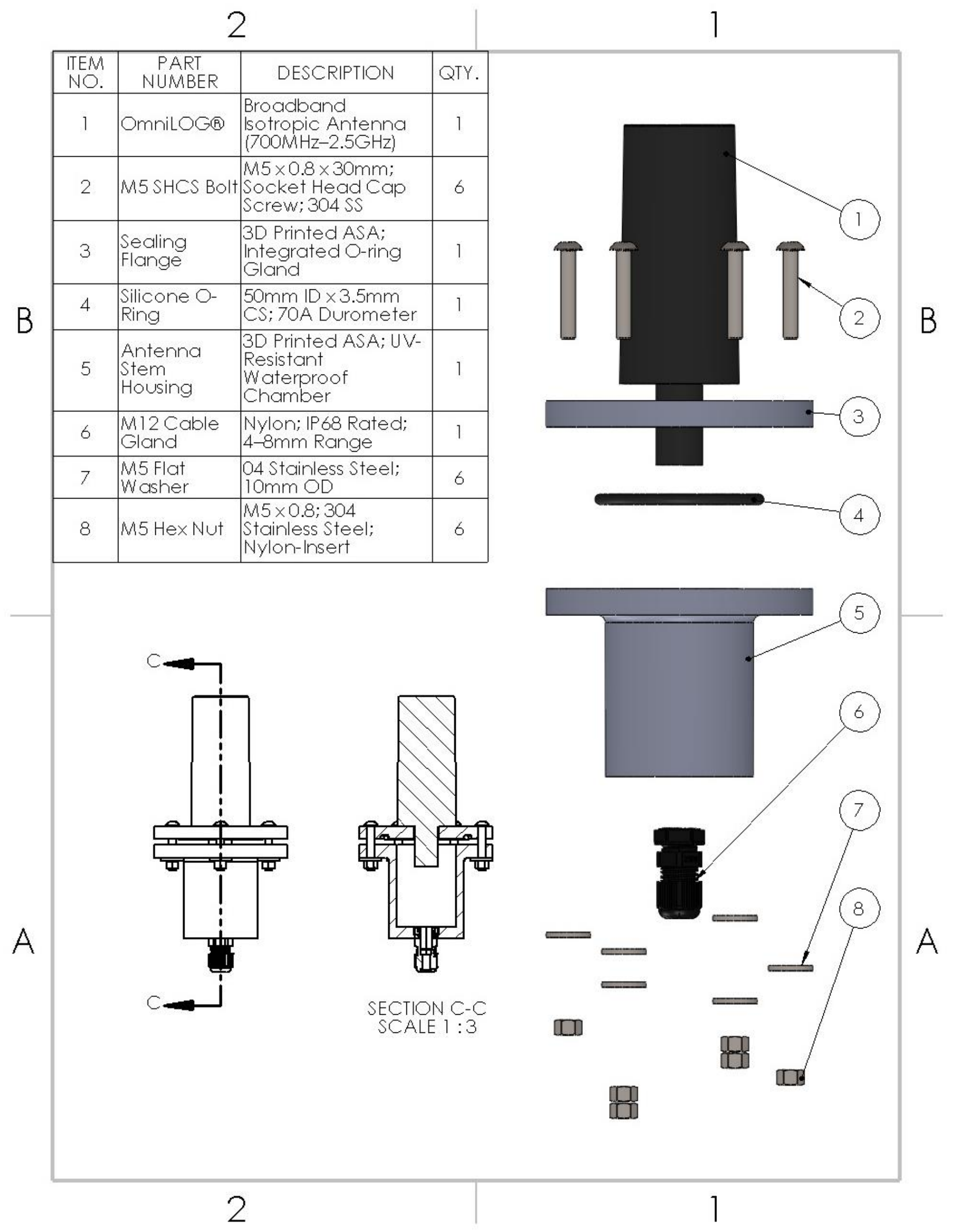


Figure [5]: Slot-Antenna Theory. (A) A seam and (B) its complementary dipole antenna (Reprinted from [1]).

Engineering a Field-Deployable Antenna Interface



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	OmniLOG®	Broadband Isotropic Antenna (700MHz–2.5GHz)	1
2	M5 SHCS Bolt	M5 x 0.8 x 30mm; Socket Head Cap Screw; 304 SS	6
3	Sealing Flange	3D Printed ASA; Integrated O-ring Gland	1
4	Silicone O-Ring	50mm ID x 3.5mm CS; 70A Durometer	1
5	Antenna Stem Housing	3D Printed ASA; UV-Resistant Waterproof Chamber	1
6	M12 Cable Gland	Nylon; IP68 Rated; 4–8mm Range	1
7	M5 Flat Washer	04 Stainless Steel; 10mm OD	6
8	M5 Hex Nut	M5 x 0.8; 304 Stainless Steel; Nylon-Insert	6

Figure [6]: FLASH Antenna Mount Assembly. An IP67-rated, 3D-printed housing featuring a custom O-ring seal and M12 cable gland to protect the OmniLOG® antenna in rugged field environments.

Figure [7]: IP67 Submersion Test. The 3D-printed antenna chamber held over a custom-built 1-meter water column to validate seal integrity and hydrostatic pressure resistance for 30 minutes.

- **Environmental Hardening:** Transitioned from PLA (polylactic acid) prototypes to production-grade ASA (acrylonitrile styrene acrylate) for long-term **UV stability**. Applied silicone grease to O-ring seal to effectively mitigate potential leak paths and ensure the **waterproof integrity** of the 3D-printed enclosure.
- **Precision Compression Architecture:** Optimized O-ring groove geometry in SolidWorks for a **zero-leak radial seal**. M5 stainless hardware and a concentric sealing stem maintain a constant-pressure interface, preventing moisture/dust ingress during outdoor thermal cycling.

Results

- **EMI Mitigation:** A shielded chassis and **precision-modeled apertures** create a "Faraday cage" effect, maintaining the nanosecond timing accuracy required for high-speed RFSoC 4x2 broadband signal digitization and transient radio frequency capture.
- **IP67 Environmental Sealing:** An integrated O-ring gland and compression-sealed antenna housing **isolate the signal chain from moisture**, ensuring hardware reliability during rigorous 1-meter hydrostatic field tests conducted for atmospheric research.

References

[1] H. W. Ott, *Electromagnetic Compatibility Engineering*. Hoboken, NJ, USA: John Wiley & Sons, 2009.

[2] Global O-Ring and Seal, *O-Ring Groove Design Guide*. Houston, TX, USA: Global O-Ring and Seal, 2026.