E-REON

ENGINEERING PERSPECTIVE

RF ECOSYSTEM PERSPECTIVE

Engineering RF Systems for UAV and Counter-UAV Technologies

Platforms, validation, integration, and subsystem development in a rapidly evolving RF ecosystem

FOCUS	PREPARED BY	TYPE
UAV / Counter-UAV RF	**E-REON**	**Whitepaper**

Table of Contents

Where this excerpt sits in the full whitepaper

This page is included to show where the current shared excerpt belongs within the full whitepaper. The highlighted entries indicate the section(s) included in this post, while the remaining entries show what comes before and after in the full document.

> **Note:** The highlighted sections below are the ones included in this post. The rest of the outline is shown only to make the document flow clear and to indicate what precedes and follows the current excerpt.

1. Executive Summary

Engineering focused perspective on where the RF ecosystem enables rapid progress, where bottlenecks emerge, and where subsystem-level support becomes valuable.

The RF landscape surrounding UAV and counter-UAV technologies is evolving rapidly. The widespread availability of software-defined radios, RF modules, signal generation hardware, and other accessible building blocks has made experimentation significantly easier than in the past. This has lowered the barrier to entry for many organizations exploring UAV communications, RF sensing, GNSS-related resilience testing, interference studies, and counter-UAV concepts.

In many cases, such building blocks are the right place to start. In some simpler scenarios, they may even be sufficient for early deployment or internal evaluation. They allow teams to test ideas quickly, gain operational understanding, and begin shaping technical requirements before committing to more specialized subsystem work.

However, the transition from experimentation to reliable use is rarely straightforward. As projects move beyond basic concept validation, engineering bottlenecks begin to appear. Advertised RF performance may differ from measured behavior. Thermal limits may only become visible under sustained operation. Multi-channel integration can expose filtering, shielding, control, and stability issues.

Field use may reveal a gap between what works on the bench and what performs predictably in a deployed environment. These challenges are not unusual; they are a recurring part of how RF systems in this domain evolve.

> **Central point:** Accessible RF hardware makes experimentation easier, but reliable subsystem use depends on validation, integration, and engineering depth.

EARLY ADVANTAGE	RECURRING BOTTLENECK	MAIN NEED	ENGINEERING ROLE
Rapid Experimentation	**Subsystem** Maturity	**Validation** & Integration	**Risk** Reduction

PRACTICAL DEVELOPMENT GAP

This creates a practical gap in the development process. On one side, there is a growing ecosystem of available RF hardware that enables fast experimentation. On the other, there is the need for better-understood, better-integrated, and more reliable subsystems suitable for repeatable testing, structured development, and more demanding operational contexts.

Between these two ends, many teams need support not necessarily to replace the available ecosystem, but to evaluate it, validate it, integrate it, and build on it more effectively.

What This Means in Practice

- Measure real performance, not only advertised values
- Understand thermal and duty-cycle limits
- Reduce multi-channel integration uncertainty
- Improve repeatability in testing and deployment
- Clarify what third-party hardware can and cannot do

E-REON's Role in This Transition Space

E-REON's role sits in that transition space. The company does not position itself as a universal supplier for every part of the UAV or counter-UAV stack. Instead, it contributes where RF subsystem understanding, engineering judgment, and multidisciplinary integration become important.

This can include RF front ends, up- and down-conversion stages, filter banks, SDR-linked RF integration, validated experimentation platforms, support equipment, and subsystem-level engineering across RF, thermal, control, and packaging domains. It can also include helping customers evaluate third-party RF hardware so they better understand what they are using and what limitations or integration burdens may come with it.

POSSIBLE CONTRIBUTION AREAS

- RF front ends and subsystem blocks
- Up/down conversion and filter-bank development
- Integration of SDRs with analog RF sections
- Validated experimentation and support platforms
- Thermal, control, and packaging-aware subsystem development
- Evaluation of external RF modules and hardware chains

FORMS OF SUPPORT

For some organizations, this support may take the form of engineering contribution to subsystem development.

For others, it may involve practical test infrastructure, validation support, or access to tested equipment that allows controlled experimentation without requiring deep in-house RF specialization from the start.

In all cases, the objective is not to overstate capability or to dismiss existing market options, but to help reduce uncertainty and improve the quality of technical decisions as projects mature.

Reading This Document

This document reflects that perspective. It is not intended as a static map of a fast-moving domain, nor as a claim that one development path fits all programs. The UAV and counter-UAV environment is shaped by rapid technical change, evolving sourcing realities, shifting deployment constraints, and a continuous adaptation cycle.

For that reason, this paper should be read as a structured engineering perspective: an attempt to explain where the current RF ecosystem creates opportunity, where it creates bottlenecks, and where an engineering partner such as E-REON can contribute meaningful value.

At a Glance

The purpose is not to replace the existing RF ecosystem, but to help customers evaluate it more clearly, integrate it more effectively, and mature beyond its limitations when system demands become more serious.

2. A Rapidly Evolving RF Environment

Acceleration, accessibility, and adaptation

The UAV and counter-UAV RF domain is shaped by unusually fast technical change. New platforms, changing operating methods, accessible RF building blocks, evolving sourcing conditions, and short adaptation cycles all influence how systems are developed and evaluated. This acceleration is not driven by technical curiosity alone, but by growing operational pressure across security, public-safety, infrastructure-protection, and defense environments. As low-cost unmanned systems become more widely available and more readily adapted to real-world use, RF development is being pushed to evolve at a pace rarely seen in more stable sectors. As a result, technical assumptions in this space often have a shorter lifetime than in other engineering domains.

2.1 More drones, more missions, more RF density

The first reason this RF environment is evolving rapidly is simple: there are more unmanned systems in use, more mission types being assigned to them, and more organisations building capabilities around them. What was once a narrower specialist domain has become relevant to commercial operators, public-safety users, infrastructure-protection stakeholders, research teams, and defence programmes alike. As the number of platforms, operators, and operational scenarios increases, the RF environment becomes more crowded, more dynamic, and more important to understand at system level.

This growth matters not only because it increases the number of airborne platforms, but because each platform can bring multiple RF functions with it. A modern UAV may depend on command-and-control links, telemetry, payload data transmission, positioning support, remote identification, and other digital service layers that extend beyond a simple pilot-to-aircraft connection. On the counter-UAV side, this creates a corresponding demand for RF sensing, signal classification, link analysis, geolocation, and other methods for understanding what is present in the airspace and how it is operating. The result is not just "more drone traffic," but a denser and more information-rich RF scene in which far more signals, emitters, receivers, and service interactions must coexist.

In Europe, this trend is reinforced by the gradual emergence of U-space, which treats drone activity as part of a digitally managed airspace environment rather than as a loosely separated niche. In designated U-space airspace, operations are tied to mandatory services such as flight authorisation, geo-awareness, network identification, and traffic information. That changes the character of the RF and communications environment. Drone operations are no longer defined only by the onboard radio link, but increasingly by the surrounding service framework that supports identification, coordination, situational awareness, and safe integration with other airspace users. In practical terms, the airspace becomes not only busier, but more connected, more structured, and more dependent on continuous information exchange.

The same acceleration is visible from the security and defence side. European defence planning now treats autonomous and unmanned systems as a major capability area requiring faster development, greater interoperability, and continuous experimentation to convert technical ideas into operationally useful systems. That has a direct RF consequence. When programmes evolve quickly, mission profiles change quickly, and operators seek practical advantage on short timescales, the associated RF architectures also change quickly. Link requirements, signal-management priorities, integration choices, and support equipment do not remain static for long, because they are being shaped by operational pressure rather than by slow, stable product cycles.

CORE INSIGHTS

For that reason, the RF landscape around UAV and counter-UAV technologies is no longer driven only by isolated radio design decisions. It is being reshaped by the combined effect of platform proliferation, mission expansion, denser airspace use, digital airspace-management services, and faster security-driven adaptation. That combination creates sustained RF pressure: more links to manage, more emissions to interpret, more coexistence problems to solve, and a shorter lifetime for static assumptions about how the airspace and its signal environment will behave.

2.2 Faster RF experimentation through SDRs, modules, and open toolchains

One of the most important changes in this domain is that many of the core RF building blocks are now far easier to access than in the past. Frequency-specific amplifier modules, signal generators, synthesizer boards, SDR platforms, filters, switches, control electronics, and supporting hardware are available through a much broader ecosystem than was previously the case. This has made it possible for organizations to begin RF experimentation without first committing to a fully custom hardware program.

This accessibility matters not only because of cost, but because of speed. Hardware that once required long design cycles can now often be assembled into a first experimental setup using available modules and standard supporting equipment. For research groups, startups, integrators, and smaller technical teams, this has significantly reduced the threshold for exploring communication links, interference concepts, front-end arrangements, and SDR-based architectures.

A second consequence is flexibility. Because many of these building blocks are modular, teams can combine and reconfigure them relatively quickly as requirements change. Different frequency bands, signal paths, amplification stages, and control approaches can be tested without redesigning every subsystem from the ground up. This has encouraged a more iterative style of RF development, in which practical experimentation begins earlier and architectural ideas can be evaluated more directly.

A further consequence of this accessibility is that entry into serious RF work is no longer limited to organizations with the resources to begin from fully bespoke hardware. Universities, smaller companies, research groups, and integrators can now build early capability through SDR platforms, common hardware drivers, evaluation software, reference designs, and stocked RF development hardware. The practical change is not only wider access to components, but a shorter path from idea to instrumented experimentation. In the UAV and counter-UAV domain, this allows teams to evaluate command-and-control links, telemetry paths, payload downlinks, GNSS-related behavior, RF sensing concepts, and interference or mitigation approaches much earlier in the development cycle.

Open toolchains are part of this acceleration as well. Common SDR frameworks, scripting environments, hardware drivers, and measurement-automation tools make it easier to configure waveforms, control devices, log results, and compare architectures without first building a fully proprietary development environment. In the UAV and counter-UAV domain, that reduces friction when evaluating command-and-control links, telemetry chains, payload downlinks, GNSS-related behavior, and RF countermeasure concepts.

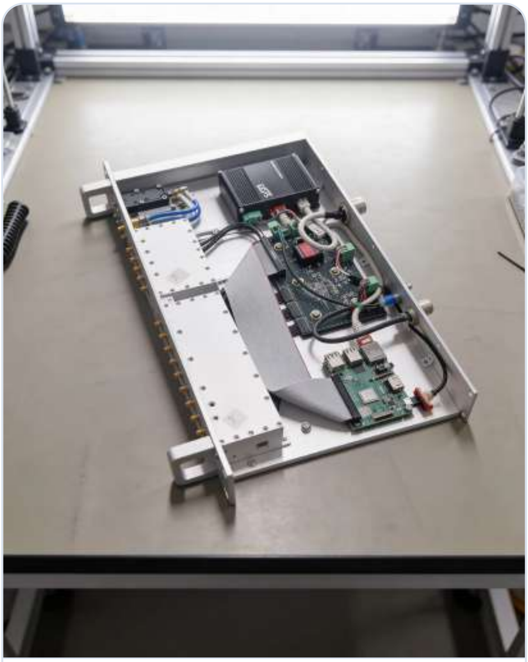

Figure 2.1 — E-REON-developed rapid RF test assembly for subsystem evaluation and early-stage experimentation.

Engineering Perspective

Importantly, easier access should not be interpreted as a weakness in the ecosystem. On the contrary, it has played a major role in accelerating experimentation and enabling more organizations to enter the field. In many cases, these available building blocks are the correct starting point. The main engineering question is usually not whether they should be used at all, but how well they are understood, how they behave in the intended operating context, and how far they can credibly support the next stage of system development.

2.3 From simple RC links to multi-layer RF architectures

Modern drone RF is no longer best understood as a single radio-control link between an operator and an aircraft. In many current systems, the RF architecture is divided into multiple functional layers operating at the same time. These can include a command-and-control path for flight authority, a telemetry path for status and health reporting, one or more payload or video downlinks, identification-related signaling, and in some cases interaction with wider network or airspace-management services. The result is a communication structure that is broader and more system-like than the traditional notion of pilot-to-aircraft control.

C2 LAYER
Flight authority, continuity, and predictable operator control.

TELEMETRY LAYER
Status, health reporting, diagnostics, and flight awareness.

PAYLOAD LAYER
Video, sensor streams, and mission-related data exchange.

Each of these layers serves a different purpose and brings different technical demands. Command-and-control links typically prioritize continuity, low latency, and predictable behavior. Telemetry paths support monitoring, diagnostics, and flight awareness. Payload links may need to carry higher data rates for video, sensor streams, or mission data. Identification functions add outward-facing signaling requirements that are not primarily about piloting the aircraft, but about making the platform visible and understandable within a wider operational environment. As these layers accumulate, the RF subsystem becomes less like a single channel and more like a coordinated communications stack.

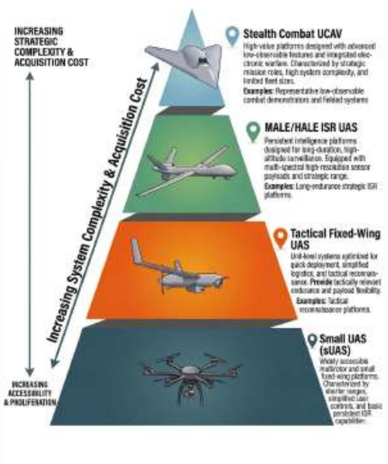

Figure 2.2 — Illustrative view of the shift from a simple control link to a broader multi-layer UAV communications architecture.

This shift is especially important for longer-range, more automated, or more operationally integrated UAV use. As missions expand beyond simple local operation, communication architectures increasingly have to support handover between links, backup communication paths, relay or mesh concepts, network-assisted operation, and compatibility with digital service layers outside the aircraft itself. In that sense, the modern UAV is no longer using RF only to receive instructions, but also to maintain connectivity, exchange operational data, and remain integrated with the surrounding mission framework.

A similar change is visible in how airspace integration is evolving. Drone operation is increasingly associated with identity, awareness, and coordination functions that reach beyond the core flight link. This means that the aircraft is not only communicating with its operator, but may also participate in a wider information environment that supports visibility, monitoring, and safe coexistence with other users of the airspace. The RF dimension of drone operation is therefore becoming broader, more distributed, and more interconnected than in earlier generations of systems.

COUNTER-UAV CONSEQUENCE
A richer airborne RF architecture creates a richer observable RF surface for detection, classification, and analysis.

This has direct consequences for counter-UAV work as well. When airborne RF architectures become more layered, the observable RF surface becomes richer. Detection, classification, and analysis are no longer limited to finding a single control transmission. They may involve interpreting command paths, telemetry behavior, payload transmissions, identification signals, and patterns of network interaction. For that reason, modern UAV RF evolves not only because radio hardware is improving, but because the role of the RF subsystem itself has expanded. What was once mainly a control link is increasingly a multi-layer architecture that supports flight, awareness, data exchange, and operational integration at the same time.

2.4 RF countermeasures reshape link design through a move–countermove cycle

RF countermeasures do not act on a static target. They act on the way a drone system exposes itself through control links, telemetry, video transmission, identification signals, and navigation-related dependencies. Once those emissions can be detected, classified, localized, or disrupted, they stop being neutral technical features and become operational vulnerabilities. That changes design behavior. Link structures, activation timing, frequency choices, transmission patterns, and even the amount of RF exposure tolerated during a mission begin to shift because they are now shaped not only by performance, but by survivability.

MOVE–COUNTERMOVE LOGIC

Once airborne emissions become readable, localizable, or disruptable, RF behavior is no longer optimized only for performance. It is also shaped by exposure, survivability, and the need to remain harder to interpret.

One important reason the landscape keeps moving is that RF counter-UAS systems increasingly aim to understand the link, not merely sense energy in the air. In practical terms, this means recognizing whether a signal belongs to command and control, telemetry, or video transmission, and in some cases building enough confidence to identify the drone family, the remote controller, or the operator's location before the aircraft has even become the main visible threat. When early warning improves and geolocation becomes more reliable, the operational cost of emitting rises. That encourages lower-signature operation, shorter transmission windows, more disciplined activation, greater separation between operator and vehicle, and wider use of relay or network-assisted architectures that make the RF footprint harder to interpret directly.

A second reason is that mitigation is becoming more selective. Broad jamming still exists, but it is no longer the only relevant model, and in many environments it is not the most attractive one. More targeted approaches attempt to interfere with the control relationship itself, exploit protocol behavior, or apply effect only where operationally necessary. As countermeasure systems become more precise, simple assumptions such as "encrypt the link" or "change band and you are safe" become less durable. Designers then respond with more complex fallback logic, different signaling behavior, stronger separation between functions, and architectures that do not depend on a single continuously exposed RF path. In that sense, the move–countermove cycle does not merely change frequencies; it changes how drone communication is organized.

Figure 2.3 — Field-deployable RF system illustrating practical counter-UAV capability in an operational form factor.

The cycle is reinforced further by the fact that countermeasure pressure affects both airborne and ground-side decisions. If remote controls, video downlinks, or telemetry streams can reveal position, intent, or operator presence, then the whole mission chain becomes subject to redesign. Some systems move toward multilink communications, some toward frequency hopping or stronger anti-jam behavior, some toward higher autonomy and shorter control loops, and some toward reduced dependence on persistent RF contact altogether. The result is that countermeasures do not simply remove drones from the air; they reshape what "acceptable" RF behavior looks like on both sides. This is why the landscape evolves continuously rather than settling around one stable architecture.

AIRBORNE RESPONSE

Link behavior may shift toward lower signature, shorter emission windows, multilink operation, fallback logic, stronger anti-jam behavior, and reduced reliance on continuously exposed RF paths.

GROUND-SIDE RESPONSE

Detection, geolocation, protocol interpretation, and selective RF effect increasingly shape how operators, remote controls, and support chains are positioned and used in the mission framework.

There is also a civil and safety dimension that accelerates change. In dense or mixed-use environments, RF effects cannot be considered in isolation from other users of the spectrum, friendly systems, navigation services, or legal operating boundaries. That pushes the market away from purely brute-force thinking and toward better discrimination, better situational awareness, and more controlled use of RF effect. As soon as countermeasures must become more selective and accountable, drone links must also become more adaptive and resilient. For that reason, RF countermeasures do not merely respond to the UAV problem; they actively drive the rapid evolution of the UAV RF environment by changing the cost, risk, and viability of different communication behaviors.

> **Key point:** In this domain, countermeasures do not only act against drone links. They feed back into how those links are structured, exposed, managed, and redesigned, making the RF environment inherently adaptive rather than stable.

2.5 GNSS interference and resilient navigation/communications

Positioning and navigation have become part of the RF problem because many modern UAV functions no longer depend only on a command link. They also depend on continuous access to trustworthy positioning, navigation, and timing information. When that layer is disrupted, the effect is not limited to map accuracy. It can influence route keeping, hold patterns, return-to-home behavior, geofencing, mission execution, and the aircraft's overall ability to remain predictable in shared airspace. In that sense, GNSS is no longer just a navigation aid in the background; it is part of the operational RF environment on which the behavior of the system increasingly depends.

Figure 2.4 — Field-deployable GNSS interference system highlighting the growing role of navigation disruption in the wider RF environment.

INTERFERENCE BEHAVIOR

This matters because GNSS interference does not always appear as a simple loss of service. Jamming can reduce availability or continuity, while spoofing can create misleading confidence in an incorrect position or trajectory. From an engineering perspective, that distinction is critical. A system that merely loses navigation may trigger one recovery behavior, while a system that trusts false navigation data may trigger a very different one. As a result, resilient UAV design can no longer assume that navigation failure is always obvious. It must increasingly consider degraded, misleading, or contested navigation states as part of normal system-level risk analysis.

NAVIGATION AND COMMUNICATIONS

Navigation resilience is also closely tied to communication resilience. If a UAV loses confidence in its position, it may change altitude, loiter, return, switch modes, or place greater reliance on the command-and-control path. Conversely, if the communication link is disrupted, the aircraft may depend more heavily on onboard navigation logic to continue safely or to recover. This means that communication design and navigation design can no longer be treated as separate engineering questions. In contested conditions, they interact directly, and the weakness of one layer can quickly increase the burden on the other. That is one reason why the RF landscape keeps changing: designers are no longer optimizing only for link performance, but for combined behavior under degraded communications and degraded positioning at the same time.

The practical response is a shift toward layered resilience rather than dependence on a single navigation source. This can include better interference awareness, more selective antenna techniques, tighter front-end protection, inertial backup, sensor fusion, alternative positioning references, and control logic that degrades gracefully when confidence in navigation drops. The objective is not to eliminate GNSS dependence entirely, but to avoid architectures in which the loss or corruption of one RF-derived input causes disproportionate operational instability. For UAV and counter-UAV development alike, this makes resilient navigation a core subsystem question rather than a specialist add-on.

WHY IT MATTERS

For that reason, GNSS interference is now shaping the RF environment far beyond the navigation receiver itself. It affects how missions are planned, how recovery logic is defined, how countermeasures are evaluated, how airspace risk is assessed, and how much trust can be placed in autonomous or semi-autonomous behavior during disruption. Once positioning integrity becomes uncertain, the engineering problem shifts from simple connectivity toward broader operational robustness. That is why positioning and navigation have become part of the RF landscape, and why resilient communications can no longer be separated from resilient PNT design.

2.6 Why brute-force RF effect breaks down in mixed-use airspace

Another reason this RF environment evolves quickly is that drone and counter-drone systems increasingly operate in environments where RF effect cannot be considered in isolation. Other spectrum users, friendly systems, navigation services, and legal operating boundaries all constrain what can be transmitted, sensed, or disrupted. In such conditions, the engineering question is no longer only whether enough RF effect can be generated against a target link, but whether that effect can be applied in a controlled way without creating unacceptable secondary effects elsewhere. For that reason, brute-force approaches become less attractive as deployment moves from isolated demonstration toward real operational use.

This matters at more than one level. At the local system level, high-power RF effect can create self-interference by desensitising nearby receivers, disturbing GNSS reception, coupling into adjacent electronics, or forcing difficult compromises in antenna placement, shielding, filtering, and timing. At the wider operational level, the same effect can interfere with friendly radios, navigation-dependent functions, safety-related services, or other legitimate spectrum users in the surrounding environment. As a result, engineering effort shifts away from raw power alone and toward discrimination, situational awareness, selective application of RF effect, and better management of when, where, and how electromagnetic exposure is created.

That pressure changes design behaviour on both sides. Counter-UAV systems are pushed toward better classification, tighter control of RF effect, and greater accountability in mixed-use environments. UAV systems, in turn, are pushed toward lower observability, more resilient link behaviour, and architectures that remain functional under congestion, disruption, or selective interference. The result is that the RF environment evolves not only because technologies improve, but because acceptable RF behaviour becomes harder to achieve when effect, coexistence, survivability, and operational safety must all be balanced at the same time.

THE BIG PICTURE

In mixed-use airspace, the challenge is no longer simply how to generate RF effect. It is how to generate enough effect against the target without degrading the wider system in which both friendly and non-target users must continue to operate.

2.7 Early RF Assumptions Require Revalidation

By this stage, a consistent pattern becomes visible: early RF assumptions in UAV and counter-UAV development often require revalidation sooner than in more stable engineering domains. This is not only because hardware evolves quickly, but because link architectures, navigation dependencies, signal behavior, deployment constraints, and practical testing priorities can all shift within relatively short periods. As a result, an assumption that appears valid during one stage of development may become incomplete or misleading once the operating context changes.

The main reason for rapid assumption decay is that development in this domain is adaptive rather than stable. Communication methods, signal paths, mitigation techniques, navigation dependencies, and deployment practices do not remain fixed long enough for static design logic to hold indefinitely. Systems are adjusted in response to new observations, new constraints, and new countermeasures. Under those conditions, engineering relevance depends less on preserving a frozen set of assumptions and more on regularly re-evaluating whether those assumptions still reflect the current technical reality.

This pressure is reinforced by a real-world move–countermove dynamic. As detection, jamming, spoofing, and other RF measures improve, operators adapt in return through changes in link structure, frequency use, software behavior, signal management, and, in some cases, alternative control methods that reduce RF exposure. In that sense, the domain does not evolve through one-sided technical progress, but through repeated cycles of measure and countermeasure in which technical advantage is often temporary.

A further reason is that many RF decisions in this space are made under partial information. Early architectural choices are often based on available modules, limited bench testing, supplier data, emerging field observations, or evolving customer requirements. That is a rational way to begin, but it also means that some assumptions are provisional by nature. They help projects move forward, yet they are not always robust enough to remain unchanged as system expectations become more precise. This is particularly relevant in cases where feasibility, thermal margins, or subsystem interactions have not yet been fully explored.

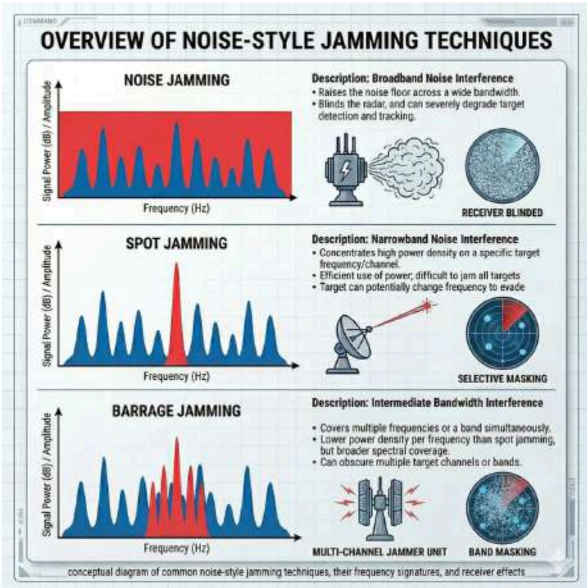

Figure 2.5 — Conceptual view of noise-style jamming techniques illustrating how RF countermeasures can drive selective responses and continued adaptation.

The structural risk is that early indications of readiness are treated as stable conclusions, even when they are only intermediate reference points. This distinction is important in RF work, where the difference between a plausible configuration and a dependable subsystem is often determined empirically rather than by appearance alone.

DEVELOPMENT STRATEGY

For that reason, this field benefits from a development approach that treats assumptions as working hypotheses rather than permanent anchors. The objective is not to eliminate early assumptions—they are necessary—but to recognize that they must be revisited as systems move from concept formation to validation, integration, and practical use.