

Solid-State Power Amplifiers for C-UAS Jamming
Key Design Trade-offs

A technical perspective for RF engineers, system integrators and C-UAS programme teams

Jamie Clark, Microwave Amps

microwave amps
Part of Nodica Group

Executive summary

Commercial and modified unmanned aerial systems are creating new technical demands for counter-UAS platforms. For RF-based defeat systems, the solid-state power amplifier is one of the most important components in the chain, influencing range, bandwidth, duty cycle, efficiency, reliability and platform integration.

Modern C-UAS requirements increasingly favour solid-state power amplifier architectures over travelling wave tube amplifiers. The shift is driven by the need for waveform agility, wide frequency coverage, lower-voltage operation, reduced maintenance burden and more robust field performance.

However, SSPA design is not a simple substitution exercise. Engineers must balance semiconductor technology, RF output power, antenna gain, thermal load, power-combining approach, packaging, environmental hardening and operational duty cycle. This article outlines the key trade-offs that programme teams and RF engineers should consider when specifying or integrating amplifier

Key takeaways

Design area	Why it matters
Semiconductor choice	GaN, GaAs and LDMOS each have different implications for power density, efficiency, cost and frequency coverage.
Bandwidth strategy	Wideband amplifier chains simplify architecture but usually compromise peak efficiency compared with band-specific designs.
Power and range	Small increases in desired engagement range can create large increases in required EIRP, thermal load and prime power demand.
Thermal design	High-duty-cycle jamming places sustained thermal stress on the amplifier module and cooling system.
Operational use case	A system designed for continuous area denial may need a different amplifier approach from one designed for reactive burst-mode operation.

Introduction why C-UAS amplifier design matters

The proliferation of commercial and modified unmanned aerial systems across conflict zones, critical infrastructure perimeters and public events has driven rapid development in counter-drone technology.

Among the suite of defeat mechanisms available, kinetic interceptors, high-energy lasers, net capture, radio frequency jamming remains the most widely deployable, cost-effective and tactically flexible option for the majority of threat categories.

At the heart of every RF jamming system sits the power amplifier. Its design influences how much radiated power the system can generate, which frequency bands it can address, how long it can operate, how much heat it must expel and how reliably it will perform in the field.

For decades, travelling wave tube amplifiers dominated high-power RF applications owing to their efficiency at microwave frequencies and their ability to deliver kilowatts of output power from a single device. However, the operational demands of modern C-UAS, rapid deployment, wide instantaneous bandwidth, software-defined waveform agility and the logistical burden of high-voltage power supplies have driven a decisive shift toward solid-state power amplifier architectures.

This transition brings with it a new set of trade-offs that system designers must navigate carefully. This article examines those trade-offs from the perspective of amplifier design, physical build and field operation, with the aim of providing a practical engineering framework for C-UAS programme managers and RF engineers alike.

> “The solid-state power amplifier is one of the most important components in the chain, influencing range, bandwidth, duty cycle, efficiency, reliability and platform integration.”



Why solid-state amplifiers are used in C-UAS jamming systems

Before examining trade-offs, it is worth establishing why solid-state technology has become the dominant paradigm in C-UAS jamming applications.

Waveform agility and wide frequency coverage

Waveform agility is perhaps the most compelling driver. Modern commercial drones and increasingly, weaponised UAS exploit frequency-hopping spread spectrum, adaptive link protocols and encrypted command channels across multiple bands simultaneously.

Defeating these systems requires jamming across wide instantaneous bandwidths, sometimes covering 433 MHz ISM, 900 MHz, 2.4 GHz Wi-Fi, 5.8 GHz video downlink and GPS L1/L2 concurrently.

SSPAs, particularly those built on gallium nitride technology, are intrinsically broadband devices capable of spanning multiple octaves of bandwidth within a single amplifier chain, a property that TWTAs cannot easily match.

Logistics, voltage and field reliability

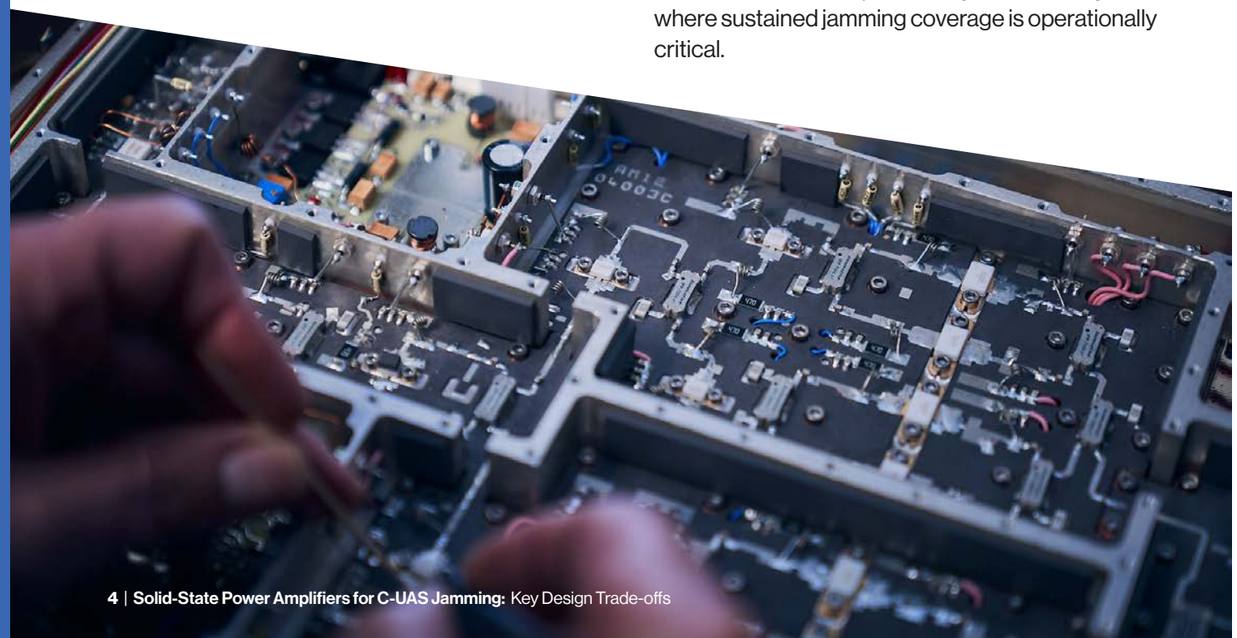
Logistics and form factor represent a second critical advantage. TWTAs require high-voltage power supplies, are sensitive to shock and vibration, and have finite cathode lifespans measured in thousands of hours.

Solid-state devices operate from low-voltage DC rails, are robust to mechanical shock and have no wear-out mechanisms under normal operating conditions. This translates directly into reduced logistical burden and higher operational availability, factors of considerable importance in forward-deployed C-UAS configurations.

Graceful degradation under partial failure

Graceful degradation under partial failure is a further advantage of SSPA architectures. A spatially combined array of solid-state amplifier modules will experience gradual output power reduction as individual modules fail, rather than the catastrophic total loss associated with a single TWTA device.

This characteristic is particularly valuable in systems where sustained jamming coverage is operationally critical.



GaN vs GaAs for C-UAS power amplifiers

The choice of semiconductor technology is the foundational design decision for any C-UAS SSPA. It has profound implications for power density, efficiency, frequency coverage, thermal performance and cost.

Gallium nitride: power density and thermal robustness

Gallium nitride high-electron-mobility transistors on silicon carbide substrates have become the technology of choice for many modern C-UAS jamming applications above 1 GHz.

GaN's material advantages are well established. It supports breakdown voltages typically an order of magnitude higher than GaAs, enabling operation from 28–50 V drain supplies and delivering significantly higher power density.

For C-UAS designers, this brings important efficiency benefits. Higher drain voltage operation improves drain efficiency because RF output power to DC input power is more favourable at higher impedance levels.

GaN's wide bandgap also improves robustness at elevated junction temperatures, helping devices tolerate the thermal stresses of high-duty-cycle jamming, provided package-level thermal management is adequate.

The trade-off is cost and supply chain maturity. Military-grade GaN-on-SiC devices remain more expensive than comparable GaAs components, with a more concentrated supplier base. For cost-constrained programmes, this remains an important consideration.

Gallium arsenide and LDMOS: where they still fit

GaAs pseudomorphic HEMTs remain relevant in specific C-UAS applications, particularly at lower power levels, in receive-path low-noise amplifiers and in applications where cost-per-watt must be minimised.

At sub-1 GHz frequencies relevant for jamming long-range UAV control links and GPS receivers, LDMOS silicon devices can also offer a compelling power-cost combination.

For multi-function C-UAS systems that must cover both UHF/L-band control link jamming and S/C-band video link jamming, hybrid architectures combining silicon LDMOS at lower frequencies with GaN at higher frequencies are not uncommon.

Designing multi-band RF amplifier architectures for C-UAS

Commercial UAS exploit a defined set of frequency bands for command and control and payload data links. A comprehensive C-UAS jamming solution must address the relevant bands either simultaneously or with rapid band-switching capability.

Typical uas frequency bands relevant to C-UAS jamming

Band	Typical application	Notes
433 MHz ISM	Long-range C2	FHSS protocols common
900 MHz ISM	Long-range C2	LoRa-based systems
1.575 GHz GPS L1	Navigation	Critical for autonomous flight
1.227 GHz GPS L2	Navigation / precision	Relevant to some advanced UAS systems
2.4 GHz	C2 and video	High density and common commercial use
5.8 GHz	Video downlink / C2	Increasing prevalence

Wideband architecture: simplicity with efficiency trade-offs

A single broadband SSPA chain covering, for example, 400 MHz to 6 GHz can provide simultaneous coverage across threat-relevant bands with a single transmit path.

This architecture minimises complexity, reduces component count and simplifies the RF switching matrix. However, achieving flat gain and acceptable efficiency across a 4-octave bandwidth is technically challenging.

The impedance matching networks required for broadband operation inevitably compromise peak efficiency compared to narrowband-optimised designs. Gain flatness typically requires additional equalisation stages that consume DC power.

In practice, fully broadband jamming solutions achieving useful output power with acceptable efficiency across the full UAS threat spectrum remain technically demanding and commercially immature.

Multi-band switched or simultaneous architecture

The more common approach in mature C-UAS platforms is a bank of band-specific amplifier chains, each optimised for its target frequency range, feeding either a combined antenna or a set of band-specific antennas.

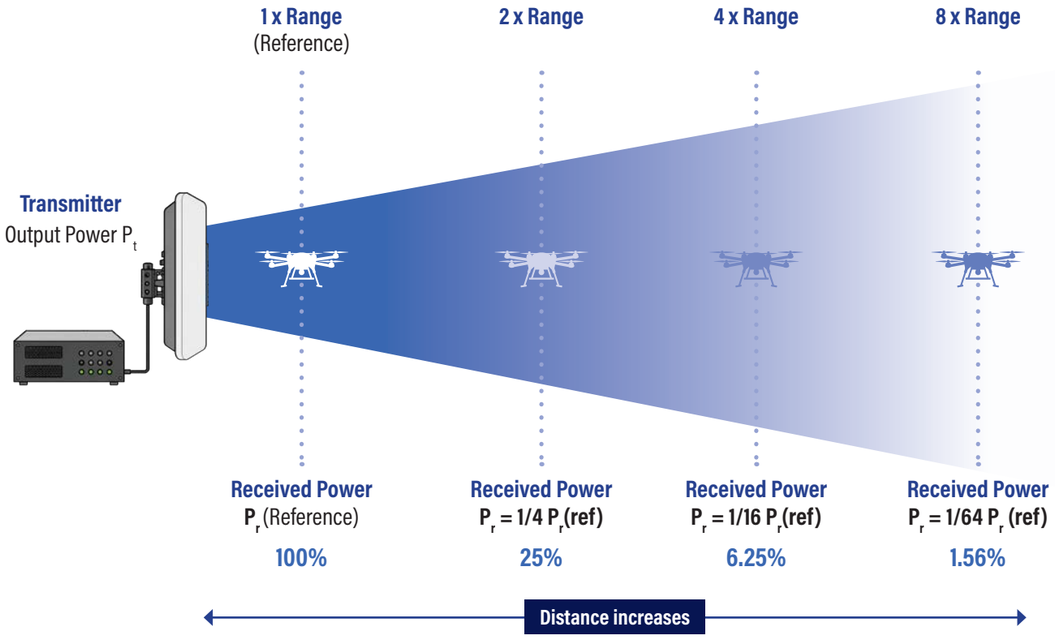
This architecture enables each amplifier to be designed for peak efficiency in its operating band, critical when total system power consumption and thermal load must be managed within the constraints of a vehicle-mounted or man-portable platform.

The trade-off is physical complexity, increased RF switching matrix design challenge and the need for inter-band isolation to prevent harmonic or inter-modulation products from one chain desensitising or damaging another.

Careful filtering at each chain output is mandatory, and the insertion loss of band-combining networks must be budgeted carefully. Every 0.5 dB of insertion loss at high power levels represents a meaningful efficiency and thermal penalty.

EIRP, antenna gain and range

How signal strength falls with distance (inverse square law)



How range, antenna gain and link budget shape amplifier sizing

A fundamental constraint governing every RF jamming system is the inverse square law. Radiated power density decreases proportionally to the square of the distance from the transmitting antenna.

For the C-UAS SSPA designer, this relationship has direct and unforgiving consequences. Doubling the effective jamming range does not require twice the transmitter output power. It requires four times the power, assuming antenna gain and target receiver sensitivity remain constant.

In practical terms, a jammer achieving adequate J/S ratio against a UAS at 200 metres must deliver four times the EIRP to maintain the same margin at 400 metres, and sixteen times the EIRP to reach 800 metres.

This quadratic scaling places an immediate and steep demand on the SSPA. Modest increases in required operational range translate into large jumps in output power, thermal dissipation, DC supply current draw and ultimately in the size, weight and cost of the amplifier module.

The relationship also cuts the other way. A UAS flying directly toward the jamming system experiences rapidly increasing signal density, meaning that systems designed for a maximum engagement range must simultaneously tolerate the near-field power levels presented by a closing target without saturating or damaging downstream components in the receive chain.

For the system engineer, the practical response is typically to prioritise antenna gain over raw SSPA output power wherever the operational geometry allows. A 3 dB increase in directional antenna gain doubles effective EIRP without any increase in amplifier output power, thermal load or prime power draw.

However, this approach trades omni-directional coverage for a narrower jamming beam, introducing a dependency on cueing accuracy and tracking speed that must be weighed carefully against the amplifier complexity it avoids.

> "Doubling the effective jamming range does not require twice the transmitter output power."



Representation of Commercial Counter Drone system

How much RF power does a C-UAS jammer need?

Determining the required output power for a C-UAS jammer requires a link budget analysis balancing jamming range, target receiver sensitivity, antenna gain and regulatory or operational constraints on radiated power.

The fundamental metric is the jamming-to-signal ratio, which must be maintained above a threshold determined by the specific UAS communication protocol being disrupted.

In free-space propagation, the path loss differential between jamming transmitter and UAS control station means that at moderate engagement ranges, output powers of 1-20 W per band are often sufficient for handheld or ground-mounted systems operating with directional antennas.

At extended ranges, or against UAS employing spread-spectrum techniques with high processing gain, output requirements can scale significantly.

This power range sits squarely in the regime where solid-state GaN amplifiers are well-suited. Single-device GaN transistors can deliver useful continuous-wave output across the 2-6 GHz range, with higher powers achievable through spatial or corporate power combining.

Power combining: corporate vs spatial approaches

When single-device output power is insufficient to meet jamming requirements, power combining is employed. The two principal architectures are corporate combining and spatial combining.

Corporate combining

Corporate combining uses passive divider-combiner networks to aggregate the outputs of multiple identical amplifier modules.

Combining efficiency is theoretically high for matched modules, but the passive network introduces insertion loss. Any amplitude or phase imbalance between module outputs degrades combining efficiency.

In high-power configurations with multiple combining levels, these losses accumulate and must be carefully accounted for in thermal and efficiency budgets.

Spatial combining

Spatial combining uses arrays of lower-power radiating elements whose fields add constructively in the far field, effectively performing the power combination in free space rather than in a passive network.

This eliminates the insertion loss of corporate combining networks and scales well to high EIRP levels.

The trade-off is increased antenna aperture size, beam-steering complexity if directional coverage is required, and the challenge of maintaining amplitude and phase coherence across the array in the presence of thermal and mechanical perturbations.

Thermal design challenges in high-duty-cycle jamming

Thermal management is arguably the most operationally consequential design challenge in C-UAS SSPA systems.

Jamming waveforms must maintain high average power to sustain effective J/S ratios, unlike radar systems that can benefit from low average power through pulse compression. This high average power translates directly into sustained thermal dissipation at the transistor junction.

Power-added efficiency and waste heat

The power-added efficiency of an SSPA is defined as the ratio of RF output power minus RF input power to the total DC supply power.

In Class AB operation, the most common operating class for C-UAS jamming applications, GaN SSPAs at 2-6 GHz typically achieve strong PAEs at rated output power under CW conditions.

At a system level, after accounting for driver stage power consumption, control circuitry, cooling subsystems and RF network losses, the overall DC-to-RF efficiency of a complete jamming transmitter is lower. The remainder is dissipated as heat.

For a multi-band system operating across several bands simultaneously, total thermal dissipation can become a significant power and packaging challenge for vehicle-integrated systems and a critical constraint for man-portable applications.

Thermal pathway and cooling approach

The thermal pathway from GaN junction to ambient environment must be carefully engineered to maintain junction temperatures within device ratings under sustained jamming duty cycles.

High-performance GaN packages use low thermal resistance paths from the transistor junction to the package flange, then through the module baseplate to a cold plate, heat sink or coolant loop.

For high-power modules, forced liquid cooling using water-glycol mixtures or synthetic coolants is often necessary to maintain acceptable junction temperatures under continuous operation.

Air-cooled designs are simpler logistically but impose larger form factors and are more sensitive to ambient temperature variation, a meaningful consideration for systems deployed in hot climates.

Thermal cycling and long-term reliability

Thermal cycling resilience is important in systems that move between standby and full-power operation. Repeated thermal expansion and contraction at solder joints and bond wires can accumulate mechanical fatigue.

Design choices including wire bond geometry, underfill materials and controlled ramp rates in power management firmware all contribute to long-term reliability under cyclic thermal loading.



Integral Cooling for DC Module

Waveform agility, linearity and efficiency trade-offs

Jamming waveforms for C-UAS applications encompass a spectrum from narrowband CW tones through chirped wideband noise to digitally synthesised representations of legitimate control signals.

This waveform diversity has implications for amplifier operating class selection.

Simple barrage noise or swept CW jamming places no linearity requirements on the amplifier. Class C or even switch-mode operation can be employed to maximise efficiency, accepting significant harmonic content at the output, which is managed by output filtering.

More sophisticated jamming techniques, including deceptive jamming, protocol spoofing or adaptive waveforms designed to minimise spectral occupancy and reduce probability of intercept, require the amplifier to reproduce complex modulated signals with adequate amplitude and phase fidelity.

In these cases, Class AB operation with appropriate pre-distortion or envelope tracking is required, accepting a moderate efficiency penalty in exchange for the waveform quality needed for the jamming technique to be effective.

The choice of jamming waveform therefore feeds back directly into amplifier design. Systems designed for waveform-agile operation must balance efficiency optimisation against linearity requirements across the full waveform library.

Packaging, PCB materials and environmental hardening

Module architecture

Modern C-UAS SSPAs are typically realised as multi-chip modules or as PCB-based assemblies using packaged transistors.

Multi-chip module approaches using bare-die GaN transistors on high-thermal-conductivity substrates offer the highest power density and lowest thermal resistance, at the cost of more demanding assembly processes and higher non-recurring engineering costs.

PCB-based assemblies using packaged GaN devices offer faster development cycles and broader sourcing flexibility, making them attractive for programmes where time-to-field is a priority.

RF PCB materials

At frequencies above 2 GHz, substrate material selection is critical for maintaining low insertion loss and predictable impedance in transmission line structures.

PTFE-based laminates offer low dielectric loss tangent and stable permittivity versus temperature but are more expensive and mechanically demanding than standard FR4.

For multi-layer boards integrating RF and digital/control functions, careful management of layer stack-up and ground plane continuity is required to prevent digital switching noise from coupling into sensitive RF nodes.

Environmental qualification

C-UAS systems are deployed across a wide range of operating environments, from arctic to desert, and must survive the mechanical shocks of vehicle transport, the humidity of maritime environments and the thermal extremes of direct solar loading on



Operational considerations for real-world deployment

Continuous operation vs burst mode

Many C-UAS scenarios involve sustained area denial, maintaining jamming coverage over an extended period to prevent UAS ingress into a protected zone.

This continuous operation mode places the SSPA under maximum thermal stress and requires that the thermal design provide adequate margin for indefinite duty cycle operation, not merely peak-power bursts.

Conversely, systems used for reactive jamming of detected threats, cueing from radar or EO/IR detection, may operate at much lower average duty cycles, enabling more aggressive peak power levels from a given thermal design.

The duty cycle profile is therefore an important input to the SSPA design specification. Systems designed for one operational mode may be significantly sub-optimal for the other.

Spectral management and collateral effects

High-power wideband jamming introduces the risk of collateral interference with friendly communications, navigation and ISR systems operating in adjacent frequency bands.

This is particularly acute in congested electro-magnetic environments, joint operating areas, urban operations or embedded force-protection scenarios.

SSPA designers must ensure adequate harmonic and spurious output suppression through output filtering, and system operators must coordinate jamming activation with spectrum management authorities where possible.

Directional antenna systems, phased arrays or high-gain directional antennas with precise pointing can concentrate jamming energy on the threat vector and reduce collateral interference in other directions.

This imposes additional requirements on the SSPA in terms of amplitude and phase matching across antenna elements but offers significant operational advantages in congested EM environments.

Power supply and prime power constraints

The prime power available to a C-UAS jamming system is often a binding constraint, particularly for man-portable and unmanned ground vehicle integrated applications.

A multi-band SSPA system drawing substantial continuous power from a vehicle electrical system will impose a meaningful load on generators or battery systems and will limit the endurance of battery-only platforms.

Careful attention to SSPA efficiency, aggressive power management and load management firmware that coordinates jamming activation with platform power status are all important elements of practical system design.

Emerging directions in C-UAS SSPA design

Several technology developments are shaping the next generation of C-UAS SSPA design.

- **Diamond substrate GaN** promises a step change in thermal performance, with diamond's high thermal conductivity enabling far higher power density than SiC-based devices. Manufacturing maturity and cost remain challenges for near-term production systems.
- **GaN-on-silicon** offers a path to lower-cost high-volume GaN devices by leveraging mature silicon foundry infrastructure. Electrical performance currently lags GaN-on-SiC, but the cost differential may prove compelling for cost-sensitive C-UAS applications.
- **Monolithic microwave** integrated circuits incorporating driver and final-stage amplification on a single GaN die are enabling more compact, reproducible SSPA module designs with reduced assembly variability.
- **Digital pre-distortion and envelope tracking** are increasingly relevant for C-UAS SSPAs operating with complex modulated jamming waveforms, enabling operation closer to the amplifier's efficiency peak without sacrificing signal fidelity.



Conclusion

The solid-state power amplifier is an enabling technology at the heart of modern RF-based counter-UAS jamming systems. The design choices made at transistor, circuit and system level have direct consequences for operational effectiveness, reliability and logistical sustainability.

GaN-on-SiC has emerged as the semiconductor technology of choice for many C-UAS SSPA applications above 1 GHz, offering the combination of power density, efficiency and thermal robustness that high-duty-cycle jamming operation demands.

However, the fundamental trade-offs between wideband coverage and band-specific efficiency, continuous operation capability and peak power, amplifier linearity and efficiency, and environmental hardening and size/weight do not have universal solutions.

> "The design choices made at transistor, circuit and system level have direct consequences for operational effectiveness, reliability and logistical sustainability."

They must be resolved in the context of the specific operational requirement, threat profile, platform constraints and programme economics of each C-UAS application.

As the UAS threat continues to evolve with increasing use of autonomous navigation, mesh networking and encrypted links, the demands placed on C-UAS SSPA technology will only intensify. Engineers and programme managers who understand these trade-offs at a fundamental level will be best positioned to deliver systems that remain effective against a dynamic and adaptive threat environment.

How Microwave Amps can support C-UAS and EW amplifier requirements

Microwave Amps designs, manufactures and tests high-reliability solid-state RF and microwave amplifier solutions for demanding applications, including radar, electronic warfare, counter-UAS, space, science and specialist industrial systems.

For C-UAS and EW programmes, the team can support amplifier selection, custom module development, power-combining approaches, thermal and integration considerations, and application-led configuration across relevant frequency bands.

With design, manufacture and test carried out in Bristol, Microwave Amps combines deep RF expertise with practical in-house delivery, helping engineers and programme teams move from requirement to reliable amplifier solution with greater confidence.

To discuss a C-UAS or EW amplifier requirement, visit www.microwaveamps.co.uk or call 01275 853196.



About the author

Jamie Clark is a recognised specialist in RF and microwave amplifier technology, with extensive experience supporting high-performance applications across defence, aerospace, communications and counter-UAS systems.

As a senior figure at Microwave Amps, he brings deep technical understanding of solid-state power amplifier design, including power output, bandwidth, efficiency, thermal performance, reliability and system integration. His expertise makes him a valuable point of contact for engineers, integrators and programme teams looking for informed guidance from a leader in the field.

microwave amps
Part of Nodica Group

Powering the Electromagnetic Domain

Microwave Amps designs, manufactures and tests high reliability solid-state RF and microwave amplifier solutions from 20MHz to 18GHz.

Based in Bristol, we have supported demanding RF applications for more than 35 years, combining proven engineering expertise with reliable performance across CW, **pulsed, wideband and high-power systems.**

35 YEARS RADIO FREQUENCY EXPERTISE

20 MHz - 20 GHz
High-reliability solid-state amplifier solutions

Made and serviced in United Kingdom

Microwave Amps Ltd
103 South Liberty Lane,
Bristol , BS3 2SZ

microwaveamps.co.uk
sales@maltd.com
+44 (0) 1275 853 196