

Multi-Mode Radar White Paper

By Mark Radford, Co-Founder & CTO - Blighter Surveillance Systems Ltd



Introduction

Traditional surveillance radars have been defined by their radar architecture and mechanical construction, resulting in application specific radar designs:

- Ground surveillance radar
- Air traffic control radar
- Coastal vessel tracking system (VTS) radar

The advancement of radar technology including availability of low-cost electronic scanning antennas, high capability and easily programmable signal processing platforms, and high-quality digital waveform generators, allows modern radars to do so much more than their predecessors. Yet, the majority of radars on the market presently offer only single mode operation or attempt to apply modes for one application directly to another application despite differences in target type and radar environments. However, there are radars now becoming available that offer the operation of all three modes, for air, ground and water, simultaneously. These multi-mode radars were once only available in multi-million-pound military systems, but are now available at a fraction of these costs.



Figure 1: Typical coastal VTS radar

Types of Traditional Radars

There are many different types of traditional radars:

- Air surveillance radars are generally used for tracking commercial aircraft movements, or in the case of air defence radars, military aircraft and missiles. Air traffic control radar (ATC) is the general term for all radar devices used to secure and monitor civil and military air traffic in air traffic management. They are usually fixed radar systems that have a high degree of specialisation. Air defence radars can detect air targets and determine their position, course, and speed in a relatively large volume of sky. The maximum range can exceed 300 miles, and the bearing coverage is a complete 360-degree circle. Air defence radars are in two categories based on the amount of position information supplied. Radars that provide only range and bearing information are known as two-dimensional, or 2D, radars; radars that give range, bearing, and height are three-dimensional, or 3D, radars. Air defence radars are used as early-warning devices because they can detect approaching enemy aircraft or missiles at great distances. Early detection is vital for successful defence against attack. Another function is guiding combat air patrol aircraft to a position suitable to intercept enemy aircraft.
- Ground radars are designed specifically to detect the movement of people, vehicles and other objects, often for perimeter security. Being ground based, the effects of terrain variation and obscuration by trees, buildings, etc. significantly affect line-of-sight range, and therefore these radars tend to be limited to no more than 30 km maximum target detection range. The radar reflections from static ground objects, such as trees, buildings and infrastructure or even natural land cover such as grass or bushes, create large amounts of ground clutter reflections that, without careful radar design, can obscure moving targets of interest in their midst. Ground radars therefore focus much effort on minimising and managing ground clutter. Narrow radar beams focus radar energy onto targets of interest while minimising the illumination of unwanted clutter and elaborate Doppler frequency filtering separates and removes the unwanted ground clutter, allowing the targets of interest to be detected.
- Shore-based maritime and coastal surveillance has traditionally been about monitoring ships that want to be seen, such as fishing boats and leisure vessels. The threat environment has evolved and immigration by boat has become a critical issue. The focus is now on tracking vessels which are trying to stay hidden; boats that are trying to evade detection by sitting low in the water, not carrying a radar reflector and operating at short ranges blind to traditional long range coastal radar systems, such as inflatables, kayaks and other small craft.

For all of these application areas, the radar capability has in the past been limited by the available technology, such as rotating antennas, valve-based transmitters, simple analogue RF waveform generation, and analogue target detection or basic digital processing, typically moving target indication (MTI), to suppress clutter. Using these, now, basic technologies it was only practical and cost effective to design the radar for one specific role.

Advancing technology

The advancement of radar technology, including availability of low-cost electronic scanning antennas, high capability and easily programmable signal processing platforms, and high-quality digital waveform generators, allows modern radars to do much more than their predecessors. The introduction of active electronic scanning array (AESA) radar technology enables the radar beam to be steered electronically so that the system does not require a mechanically rotating antenna. This provides superior performance compared to conventional systems, but, to date, most have been large systems used for military applications and are very expensive. Rotating radars are still used for many commercial applications though the price-performance benefits of non-rotating antennas are starting to see influence in the market.

Solid-state radars eliminate the magnetron and replace it with a solid-state, broadband transmitter that outputs a clean, frequency-stable signal. While legislation for cleaner spectrum encourages a move to solid-state transmitters, they also offer higher reliability and lower maintenance, but at present do come at a cost premium. However, the solid-state transmitter also allows advantage to be taken from the use of more sophisticated transmission waveforms, allowing more efficient and effective solid-state transmitters and lower mean power and electrically cleaner radio emissions.

Digital waveform generation provides greater signal precision and stability, and is designed to complement digital signal processing. This enables increased performance to be extracted from a radar. While sophisticated waveform design and generation has been used within military grade radars for several decades, the availability of low-cost chipsets and tools is pushing the capability into commercial grade products.



Figure 2: Example AESA radar

What is multi-mode radar?

The majority of radars on the market at present offer only a single mode of operation or apply the mode for one application directly to another application despite mismatches in target type and radar environments. However, radars are now becoming available that offer the operation of all three modes simultaneously and these multi-mode radars enable optimal performance in each of the three domains in which they operate: air, ground and water. The multi-mode radar needs to be able to handle simultaneously the complex operational needs of each unique environment:

- For ground surveillance, slow moving ground-based targets of interest need to be detected in heavily cluttered environments and amongst 100s or 1,000s of other moving objects.
- In the airspace domain, it is comparatively uncongested and while traditionally only manned aircraft have been of concern, the contemporary challenge is in detecting small unmanned aircraft ('drones') while filtering out and ignoring birds.
- Over water, the dominant challenge is in the removal of sea clutter, and near the shore, especially the ability to filter out the effects of breaking waves. The modern threat of small and covert boats further adds to the challenge.

The multi-mode radar necessarily needs to point its radar beam in the direction of interest either in the air or pointing down near the land or water. The multi-mode radar needs to be able to rapidly change waveforms on the fly so that for instance it can detect small hobby drones at short range with a fast update rate, while over water, still be able to detect larger boats and ships at much greater ranges. This diversity of waveforms and the need for low-latency switching of operational modes demands that much of the core radar design is digital.

Large, military grade transportable and naval multi-mode radars have been available for decades, but it is the capability of new digital technology that has allowed the size and the cost to be reduced to affordable levels. However, it is also interesting to speculate if this the tri-mode capability would have been necessary if it were not for the recent growth in the misuse of drones.



Figure 3: Military grade transportable radar

Why is multi-mode radar required?

The growth in the commercial and hobby use of drones has generated an increasing demand for precision 3D detection particularly in the case of small hobby drones. For many security applications it is the misuse of drones that has created the greatest new challenge in each of the domains. Radar is about the only non-cooperative sensor technology that can detect these hobby drones and other air, ground and water-based targets in all environmental conditions.

Ground radars traditionally look at 2D space such as open land and space surrounded by perimeter fencing, but drones demand accurate 3D spatial detection within the volume of airspace above the 2D perimeter area. Drones can be used by criminal users to observe secure areas and to check that they are clear and unobstructed for entry. But the drones are small compared to the size of ground threats such as people and vehicles, so optimised radar waveforms are necessary for effective detection. Furthermore, the drones can carry payloads, travel at high or slow speeds and can hover, with the ability to change direction quickly thereby placing new challenges on the multi-mode radar air detection capability to achieve rapid detection and alerting but with low false alarm rates.

Air radars are traditionally used to detect large (manned) aircraft. These aircraft are fast moving, physically large and generally flying at a high altitude, so long-range surveillance to many tens of km or more is a practical proposition. In general, small hobby type drones fly at altitudes below manned aircraft and as sold, have inbuilt protection to prevent flying beyond safe limits. Such geo-fencing typically limits maximum flight altitude and prevents the drone from flying in and around critical national infrastructure. But these hobby drones can fly higher or in secure areas if hacked and so it is important to know precisely where they are in airspace, since even small drones can cause significant damage to large aircraft.

Beyond the ubiquitous hobby drone, there are a huge number of other types of drones being developed to address nascent applications including, for example:

- Agricultural drones
- Delivery drones
- Air taxis
- Various safety, security, and inspection drones

In general, the commercial usage of drones will demand greater flight endurance from the drones and so there will be growth in larger multi-rotor type drones, and for certain long range and extended endurance applications, there will be increased usage of traditional winged drones. This plethora of drones, flying both close to the ground, and potentially within managed airspace, will demand effective, reliable and precision measurement of every drone, large and small.

There is now considerable effort going into developing standards for UAS traffic management (UTM), as opposed to traditional air traffic management (ATM). This will result in the requirement for all drones to carry some form of electronic identification (electronic conspicuity). But if the e-identification isn't working, or is deliberately disabled, it will inevitably require radar to detect and observe the flightpath of the rogue drone.

One would normally expect existing air traffic radars to detect air targets, but it is likely that old radars cannot be updated to detect small drones and at short distances due to the limitations of the original design and the older technology used. Detecting small drones also means that birds will be detected



Figure 4: Typical hobby drone (DJI Phantom 4)

and therefore need to be filtered out. Hobby drones fly close to the ground and require ground filtering capability for low-slow-small detection, and this is where a multi-mode radar could be used to augment the information from an existing long-range air radar.

Existing coastal radars detect commercial boats, ships and smaller boats with radar reflectors; monitor shipping lanes; track ships out of position; prevent collisions and provide guidance for vessels into ports. But there is a two-fold modern challenge; the need to detect small surface targets and drones. Illegal immigrants are often packed into small non-reflective boats sitting low in the water and which are fairly covert and not easily visible. Smugglers use semi-submersibles or unmanned surface vehicles (USV) which are far smaller than traditional boats. Drones are often used for the reconnaissance of landing areas to check that the coast is clear, and for 'last-mile' contraband drop-offs.

Significantly, environmental conditions are a real challenge for over water operation of radars. The sea, and especially the coastline, creates a uniquely variable radar operating environment. One day the sea conditions may be flat, resulting in no clutter and allowing the detection of the smallest of targets. Another day, there may be large waves, wave crests and wind-blown rain. It is less likely that drones will fly close to the water in these conditions, but it might be a good time to try and smuggle goods as they are less likely to be detected. It is much more difficult for radars to detect small drones and USVs from the surrounding marine environment, although modern Doppler radars enable drone velocity to be discriminated from waves.

There are no traditional radars that can address all these threats. Ground based mechanical scanning radars cannot detect crawlers or drones due to minimum velocity and minimum target size limitations. Coastal surveillance radars cannot detect small objects along the shoreline as they often have a shadow area under their antenna coverage or a short-range dead-zone due to transmitter waveforms. Air traffic control radars cannot detect drones. There is a need to move to new technology, and also to a multi domain capability.

How can the multi-mode radar help?

There are not many locations that require simultaneous air, ground and water radar coverage at one site, however it is the ability of the radar to be able to manage the three modes that also allows it to offer effective ground and air, or coastline and air surveillance.

There are many coastline-based military and government sites that would benefit from this capability, such as naval bases, firing ranges, sensitive coastal locations, and nuclear facilities. Estuaries and other tidal areas would also benefit from automatic switching of radar modes.

Multi-mode radars offer traditional radar capabilities while at the same time allowing extended capabilities including drone, covert boat and crawler detection. The radar can apply its different modes depending on where it is looking. Radar beams pointing upwards will use air modes. This allows optimised drone detection, without significant ground clutter management. Radar beams pointing horizontally or even downwards will use ground or coastal modes. This allows surface clutter to be optimally filtered while still being able to detect drones. The switch between ground and coastal modes can be made automatically based on geographics inputs from a regional coastline map.

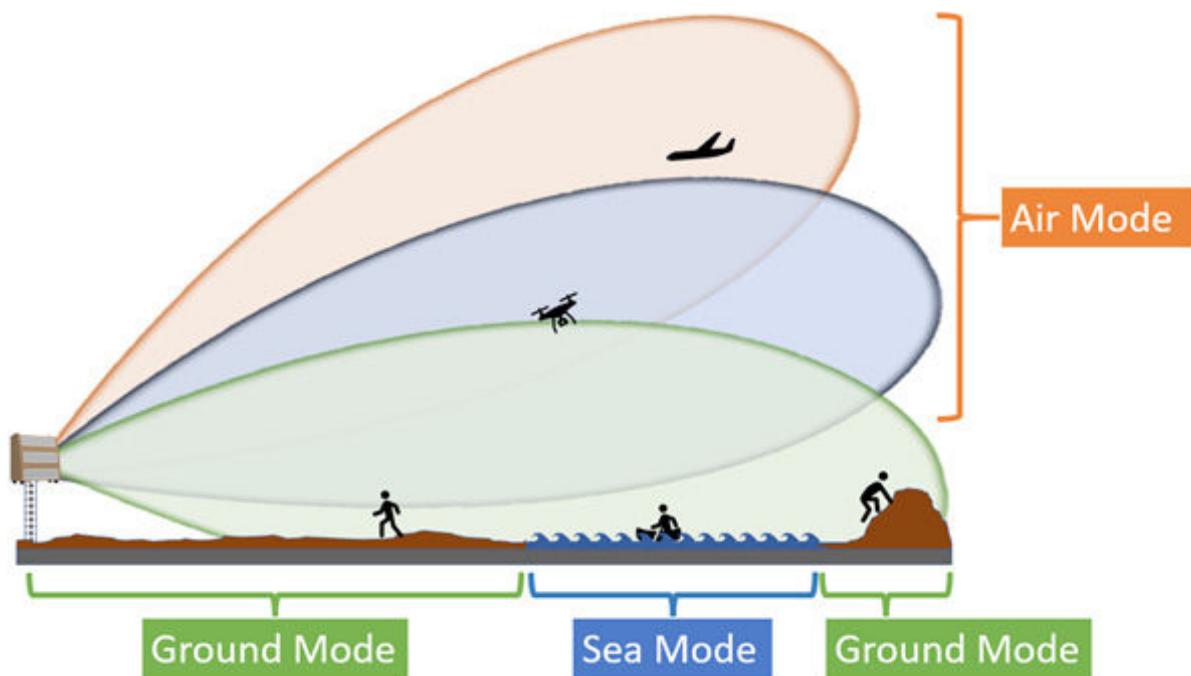


Figure 5: How the Blighter A800 tri-mode radar automatically applies different operational modes depending on the target zone

What multi-mode radars exist?

Some of the large military grade radars are multi-functional, but they are not covering short to medium range targets and cannot address modern threats like small drones. Blighter Surveillance Systems has the technology to address modern threats but to date there are few radars claiming to be able to cover all three domains, air, land and sea. The technology has existed but has not been affordable or accessible. Only recently has Blighter been able to combine these capabilities together; with the newly launched A800 3D multi-mode radar, the three modes can operate simultaneously.

Blighter's A800 radar harnesses the multi-mode simultaneous scanning capability of large-scale but costly radar antennas, and packages it into a smaller, much more accessibly priced radar with a maximum range of 10 to 20 km, including 6 km for small Group 1 drones and 2 km for micro UAS. The A800 is geared towards border surveillance and base security, particularly in the military domain and in locations where there is a requirement for scanning air, land and sea simultaneously from a single radar.

Even the largest, most advanced radars along a coastline have a range of around 10 km for small covert vessels, meaning for thorough surveillance of an extended area, radars would need to be placed every 10 to 15 km. Blighter's A800 has been designed for this purpose, offering density of cover for the modern threat. Instead of having a small number of large, long-range radars, with Blighter's multi-mode capability, customers will be able to use multiple low-cost multi-mode radars, each able to detect low, slow and small land and waterborne threats, as well as, crucially, small airborne drones up to 6 km away.

Blighter's multi-mode radar offers an effective and affordable way to cover large areas, scanning air, land and sea simultaneously and detecting small and slow threats in each domain alongside traditional threats, including consumer 'hobby' drones which are currently acknowledged to be the key challenge for contemporary radar platforms.



Figure 6: Blighter A800 tri-mode radar

The future?

As the nature of threats evolve, so too must the capability of the radar systems needed to detect them. Future radars will be more compact, and lower cost. Traditional surveillance radars were only concerned with larger targets: people, vehicles, commercial boats, manned aircraft, and have the ability to detect these at ranges of tens of km. But consumer drones are typically 1,000th (even 1 millionth) of the size of a human, and so the maximum detection ranges will be much reduced to 2 to 5 km at most. Instead of using a small number of large, long range radars, multiple low-cost, dispersed multi-mode radars will be used. These may be networked to share and fuse target information to create a comprehensive land, coast and air 3D situational awareness picture.

About the Author



Mark Radford is the technical Co-Founder and Chief Technology Officer (CTO) of Blighter Surveillance Systems Ltd.

Mark has worked in the radar industry since 1985, initially as a designer of high-performance signal processing solutions for naval radar systems and later as a system designer and development manager. Since moving to Cambridge, UK, in 2000, Mark has been involved in various radar development projects including the specification, design and development of the Blighter radar family, unique electronic-scanning FMCW Doppler surveillance radars.

Since his appointment as CEO of Blighter Surveillance Systems in 2013, Mark has overseen developments of the Blighter technology to enhance it for use in more complex environments such as the heavily cluttered operational areas of airports where buildings and airport traffic limit the effectiveness of traditional perimeter security radars. Further enhancements now see Blighter radars being used for coastal security and for air security, where Blighter's ability to detect very small and slow-moving targets in heavily cluttered environments is a key technological advantage. Mark first developed the AUDS (Anti-UAV Defence System) counter-drone system in 2014, which is now the principal Short-Range Air Defence (SHORAD) system used by US DoD in their warfighting efforts and is in operational use at leading UK Airports.

Mark headed the spin-out of Blighter Surveillance Systems Ltd. from its parent company in 2015 to enable rapid business growth and in March 2019 resumed his technology leadership position for Blighter by appointment to 'Co-Founder and CTO'.

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Blighter Surveillance Systems Ltd
Iceni House
London Road
Great Chesterford
Saffron Walden, CB10 1NY, UK

www.blighter.com

hello@blighter.com

Phone: +44 1223 491122

Fax: +44 1223 491123

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Blighter Surveillance Systems Ltd
Iceni House
London Road
Great Chesterford
Saffron Walden, CB10 1NY, UK

www.blighter.com
hello@blighter.com

Phone: +44 1223 491122
Fax: +44 1223 491123