Passive Radar?

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ABSTRACT

Passive radar using illuminators of opportunity to enable Electro-magnetic sensing has roots going back to the earliest days of radar development. However, the obvious attractions of using a dedicated transmitter, a co-located receiver, operating through a single antenna has resulted in the vast majority of today's radar systems being of the "traditional" monostatic type. Nevertheless, passive radar is able to deliver aspects of capability not possible with monostatic radar and hence there has been a very significant upswing in research leading to the development of commercially available systems. However, the transition from passive radar research to routine operational use has been slower than anticipated with almost no extant examples. There are many reasons for this and their discussion forms the core of this paper. In particular, aspects relating directly to illuminators of opportunity form the central focus as it is the use of an element of the radar hardware that is outside the control of the designer and operator that is often said to be a barrier to implementation. This may also contribute to the ways in which passive radars are assessed not always being consistent with other forms of radar sensing. This is further fuelled by the relatively poor provision of evidence, both from simulation and experimentation, of routinely achieved performance together with the relative lack of maturity of the technology compared to monostatic radar.

1.0 INTRODUCTION

Passive radar is a sensing and surveillance technology that has been the subject of much research [1], [2], [3] and, more recently, serious commercial development. In terms of applications and design parameters, passive radar is as ubiquitous as traditional monostatic radar with numerous examples of very different types (e.g., [4], [5]). In fact, it is critically important to recognise that simply putting the word "passive" in front of the word "radar" in no way narrows the breadth covered by the topic. Further, almost any discussion about monostatic radar soon arrows in on specifics usually driven by application. This situation is no different for passive radar. Indeed, the specifics of an indoor system exploiting, say, a Wi-Fi router and operating at ranges of a few metres will differ enormously from those of a system making use of satellite illuminators and operating at ranges of kilometres to tens of kilometres. Hence, passive radar should be considered using the same sorts of approach adopted for monostatic radar. Here, whilst every attempt is made to be as generic as possible, where specifics dictate ease of discussion and explanation, passive radar exploiting VHF and UHF broadcast transmissions for air target surveillance will be the default "application". This is chosen as passive radar for air surveillance has received the most attention in the research literature and is consequently the furthest forward in terms of operational readiness. Passive radar exploiting broadcast VHF and UHF transmissions is attractive for both military and civilian air space surveillance as the high transmit powers enable relatively long-range target detection and tracking.

It is inherent in the passive radar concept that there are essential physical differences compared to conventional monostatic radar in a number of important respects. The most significant of these is the exploitation of illuminators of opportunity. This leads to two fundamental differences from monostatic radar. Firstly, there is a core part of the radar system that is not under the control of the radar designer or operator. Secondly, exploitation of a third-party transmitter leads to a bistatic (or multistatic) configuration rather than a monostatic geometry. It is these two defining characteristics of passive radar that provide both capability advantage and determine achievable performance. Equally, it is these two characteristics that also leads to much of the ensuing discussion around the operational use of passive radar being framed in terms that can, without great care, be very different to that the equivalent discussion around monostatic radar. This can have the consequence of passive radar being judged inappropriately and, ultimately, can misinform procurement decision making. In addition, passive and more particularly bistatic radar, does not have the breadth and depth of research behind it that monostatic radar does. This too makes assessment more complicated as, for example, the availability of target and clutter models for performance prediction are almost non-existent. Lastly, it is noted that the designs of current passive radars have their origins in demonstrators. These demonstrators show real promise but are not necessarily the best final designs for a given application. In fact, it might be concluded that passive radar is not as fully a matured topic as it, ideally, needs to be for market penetration, although it seems tantalizingly close. It is not the purpose of this paper to make the case, either for or against passive radar but, instead, (i) to suggest the same basis for assessment, whether the radar is passive or active or both, against operational requirements, (ii) to suggest a need for improvements in the modelling of passive radars and (iii) to give serious consideration to aspects that lead more directly to full maturation. Whilst it is impossible to adequately cover all aspects pertaining to the performance and its assessment in respect of passive radar, an overall approach can start to be distilled from the examples given here.

2.0 REQUIREMENTS

The initial consideration of requirements for military capability should be an expression of what needs to be achieved, normally derived and aligned with an agreed concept of operations (CONOPS). As a statement of military need, requirements should be technology agnostic. For example, a requirement might be the detection of air targets but this should never be expressed as a requirement, for example, for a camera to detect air targets. The selection of a particular form of sensor is part of the technology solution that aims to meet the requirement in the most cost-effective way. If the requirement were to be expressed as detecting air targets at ranges in excess of 100km and in all weathers and regardless of time of day, it is easy to quickly begin to eliminate sensor options that use the optical or infra-red parts of the electro-magnetic spectrum. The separation of the problem from candidate solutions is critical if the most appropriate and cost-effective solutions are to be arrived at. This would be expressed in the form of a technical specification with showing directly how requirements are met. The requirements for air target surveillance can be many and varied and will be a function of each nation or procuring agency. In this paper a number of the more critical elements of a requirement are considered for a notional air space surveillance application. The principle requirement components considered are the target set, coverage, availability and quality of information needed. Other requirements of potential importance, are introduced, especially where they might be stimulated by technological innovation, as in the case of passive radar.

2.1 Target Set

The overall military requirement for air space surveillance might be expressed in terms of establishing a reliable and robust “recognised air picture” that detects, locates and tracks all important air space objects. Thus, an element of this requirement may be to articulate the types of air target that must to be detected. This could be quite a long list encompassing a large variety of air targets from big to small. Large air targets will include civilian and military passenger aircraft, transporter aircraft, medical aircraft both fixed and rotary wing, etc. Small air targets might include fast jets, combat aircraft, small reconnaissance platforms and so forth. There could be a requirement to detect and track missiles of varying types and looking to the future it might be desirable or even necessary to include small and even micro UAVs, hypersonic missiles and non-ballistic missiles. All in all, there will be a very wide range of air targets that are capable of a very wide range of flight velocities, trajectories and manoeuvres. Indeed, the complexity and density of air space occupancy is set to change quite dramatically over the coming years and this too will be need to reflected in any requirement such that the resulting capability will be able to meet the demands of both current as well as future threat scenarios.

2.2 Coverage

Having established the list of targets that need to be detected, a second requirement is to know the region of air space over which this must occur. Often timelines, including reaction times are critical and again will be subject to evolving capabilities in the air targets themselves. Consequently, coverage might be stated in terms of a volume of space that may include the ground. It might require full 3600 azimuth coverage or alternatively could be a smaller, more limited sector. The maximum range is an important parameter that reflects the need for adequate early warning and subsequent reaction times. Range is also an important factor in determining the sensitivity required of the sensing solution. The terrain types expected might be very varied and hence there may be implications for the siting of a sensor, especially those based on line-of-sight observations. Such sensors need to be placed so that shadowing from local terrain, foliage, buildings etc. is avoided or at an acceptable minimum.

2.3 Availability

Availability, in simple terms, can be interpreted as the times when the sensor needs to detect the target set in the required region of air space. The default for this is often set such that the surveillance capability is required to be available at all times. Of course, the air space environment, which often includes a ground component, is also subject to continuous change in the form of variable weather. Therefore, even this requirement needs careful consideration, informed by the CONOPS to validate exactly what is needed in terms of availability to fulfil military operations. For example, rigid adherence to availability at all times is likely to rule out optical and infra-red systems unless ranges are quite restricted. However, there can be circumstances, such as short-range and/or predominantly fair-weather scenarios, where EO and IR might have sufficient operational advantages that outweigh an availability that is not fully 100%. Reliability also forms an important aspect of availability. No sensor is completely reliable. Indeed, most have their performance stated in probabilistic terms that represent an average and can have quite wide and often unpredictable deviations from this average. Equally, equipment, especially in harsh environments, will have a limited lifetime so hardware availability will be dependent on meantime between failures (MTB) which also needs to be an aspect of the stated requirement.

2.4 Information Quality

Here, information quality refers to the type of target specific data that is required. This could be expressed in terms of location accuracies which might be in two- or three-dimensional space. It can also be expressed as tracking accuracies, including track initiation times, tolerable numbers and frequencies of track breaks and track deletions. More detailed target information may also be required such as target type. This can be divided into the NATO categories of classification, recognition, identification, characterisation and fingerprinting. Again, a well worked out CONOPS will lead to a statement of requirements articulating those aspects which must be satisfied and those where it is desirable they are satisfied. Inevitably, the greater the detail and quality of target information required, the more likely it is to push the solution into the realm of exotica that can become prohibitively expensive. A further key requirement is the detection of movement often expressed in terms of the slowest expected velocity target, velocity resolution and update rates (although, fastest movement and types of movement are just as important). It is also noted here that velocity measurement is further exacerbated in radar where it is the instantaneous radial velocity of a target that is measured by monostatic radar and the bistatic bisector target velocity with bistatic radar. This means measured velocities are almost always less than those of the target's physical velocity. It is also noted that passive optical sensors are nowhere near as well suited to velocity measurement as is radar.

2.5 Other Requirements

Other requirements might include systems to be re-locatable or even operate on the move or short-halt. They may include compatibility with other equipment's either within a nations inventory or as part of a multinational collaboration. This implies interface standards and allowance for desired levels of interoperability such as in the hand-over of target coordinates. Other requirements might include a need to be as covert as possible and to be able to detect stealthy targets - particular strengths of passive radar. The electro-magnetic spectrum itself is under ever increasing pressure and allocations to traditional use are continually changing. This is likely to be a continuing trend and may remove or restrict some active radar sensors. Naturally, cost is a key aspect of requirement and there needs to be a balance struck between capability and costs. This applies as much to through-life costs, including manpower costs, as it does to the up-front purchase cost of equipment. Indeed, even costs of disposal at end of life should be factored into budgeting. Military equipment is also often expected to have a long in-service lifetime and this means availability of spares, potential needs for upgrades both in performance and in terms of aspects such as computing infrastructure all are likely to feature as part of more detailed articulation of requirements. Overall, requirements aim to capture all necessary functionality within an achievable and realistic fiscal, temporal and legal framework.

Inevitably there are additional requirements that may feature often due to bespoke national needs but these lie beyond the scope of this paper. However, the above illustrates the wide variety and interconnectedness of military equipment that make this a complex area often needed to be supported by detailed operational research. Technology developments can also provoke new requirements in terms of a new capability that can be offered. Indeed, the invention of radar sensing itself is a good example of this. Continued technological advances will inform the setting of requirements without blurring the distinction between problem and solution.

3.0 MEETING REQUIREMENTS

It has been strongly emphasised that in describing the types of requirement for air space surveillance in section 2 above, nothing should be said about how these requirements are to be met. This is a quite separate task in which the capability-based requirements are examined against solution candidates in order to develop a cost-effective match. Indeed, the setting of requirements will be typically led by expert military personnel whilst turning this into a technical specification will be much more the domain of technical experts. The interaction between the two will also be a key feature leading to a final articulation of requirements. This can lead to questioning of the needs for some of the requirements, their prioritisation and an ultimate refinement of the overall statement of needs. This section looks at how requirements will impact potential sensor system solutions, including how technology options (and even technology developments) are able to be assessed on an impartial basis.

3.1 Target Set

In section 2.1 is was noted that the overall military requirement for air space surveillance might be expressed as the establishment of a reliable and robust “recognised air picture” that detects, locates and tracks all air space objects. For our purposes here, it is assumed that a radar solution (24-hour, all-weather, wide-area airspace surveillance) is required and the target set may be interpreted in terms of defining a minimum radar cross section that has to be detected with certain probabilities of detection and false alarm at maximum range. Although simplistic, it implies computation such that the chosen sensor radar parameters of transmit power, frequency, antenna gains, noise figure and integration gain provide a signal to noise ratio (SNR) that delivers the required probabilities of detection and false alarm. This, of course, assumes free-space, clutter free detection. Features such as multipath and more sophisticated clutter models can be included in a more elaborate computations but the basic desire to achieve the required levels of detection remain the same and are largely dictated by having an adequate signal to noise/clutter ratio. Note, passive radar SNR has contours based on the ovals of Cassini whereas monostatic radar is based on circles. This means that performance as a function of receiver range is different between the two, however, it doesn’t imply that one is necessarily better than the other or that one is more variable than the other – they both vary. It does mean that there can be quite a variety of radar solutions potentially embracing mechanically scanned radar, electronically scanned radar and passive radar. All, potentially, may have a variety of operating parameters such as transmitter frequency, antenna gains etc. and all may have differing performance characteristics that are only revealed at a more detailed level of analysis.

In terms of SNR, there is no reason why the mechanically scanned radar cannot meet the requirement. However, there will be a fixed revisit time that will limit the time on target, integration gain and update rate. Electronically scanned radar can dwell for longer once a target is detected (or suspected) but this will have implications for the radar timeline subsequently available for detecting and tracking other targets. Passive radar, in effect, is a form of staring radar in which the illuminating transmission floodlights a volume of space. The properties of the transmitters of opportunity will determine the available transmit power and the frequency of transmission. The time on target will be selectable dependent on the coherency of the target/radar combination and will impact achievable SNR. In other words, the basics of the requirement can, in principle, be satisfied by any of the three radar types but the details of how the requirements are satisfied, together with the inevitable compromises that occur, will collectively determine the overall performance together with the match of each option against the operational requirement.

3.2 Coverage

The volume of air space for which surveillance is required can be achieved in a number of different ways by suitable radar sensor design. Again, using the three examples of a mechanically scanned radar, an electronically scanned radar and a passive radar we can explore how a requirement is to be met. For a mechanically scanned radar a search volume can be interrogated in a number of ways but with some limitations. This might be a simple rotation in azimuth covering 3600. It might also include frequency scanning or multiple frequencies to provide coverage in the elevation dimension. The common aspect is that there is a defined revisit rate. This also means that for the vast majority of time the radar is only looking in directions where there are no targets. Electronic scanning can be much more flexible in regards of re-visit times by first forming an overall map of air targets and their locations and then choosing to re-visit zones more frequently where targets were present than zones where targets were not. In this way the radar can use its power more effectively. Passive radar is also different. Passive radar is firstly dependent on the coverage provided by the illuminator of opportunity and secondly it is dependent on the relative locations of the transmitter and receiver (or receivers). However, in the case of air space surveillance where the transmitters are likely to be broadcast VHF and UHF transmissions, the coverage is typically isotropic in azimuth and directed more towards the ground in elevation. If a digital array antenna is used to receive radar echoes then, in principle, multiple simultaneous beams can be formed and passive radar is able to see in all directions, all of the time. In other words, there is no concept of a re-visit rate. Equally, the coverage is typically directed at lower altitudes and large receive antennas will be needed to extend target detection ranges at higher altitudes. I.e., the physical size of the receive antenna will determine beamwidth and gain which, in turn, will have implications for SNR, target resolution, clutter suppression and location accuracy If the requirement has a need for counter stealth then this might demand a passive solution given the frequency range of transmitters and the excellent low-level coverage.

Overall, together with the wide range of targets of interest, it can be seen that specific requirements may well favour one or other designs of radar. However, there may be different advantages and disadvantages to each of the candidate solutions making a match to requirements something that is quite complex and subtle necessitating a deep understanding of the key issues and the setting of priorities. Equally, it can be seen that by being clear about the military requirement as distinct from the potential solution space, each candidate solution can be independently compared with one another on the same evaluation basis thus providing much needed clarity for sound procurement decision making.

3.3 Availability

Firstly, we again assume, for our purposes here, there is a requirement for long-range, wide-area, all-weather, 24-hour air space surveillance. All three radar candidates are able to satisfy the long-range, wide-area, all-weather, 24-hour aspects of the requirement. Mechanical scanning and electronic scanning are well-proven techniques with ways and means of determining hardware reliability and hence system availability. A commonly expressed concern regarding the potential for using passive radar is associated with the likely the availability of the transmitter of opportunity. Questions such as what happens if the illuminator is turned off either completely or for a short period are typical and it is entirely correct that these should be raised. However, detailed analyses of what may or may not happen within envisaged operational scenarios has not been reported and it is not clear if such studies have been conducted. Equally, availability should be considered across all parts of the candidate sensor system. The availability of a candidate solution should consider not just MTBF for critical hardware components but should also consider vulnerabilities to physical and electronic threats. Mechanically scanned radars, will have a focus on the transmitter or the scanner as potential single points of failure, making the readiness of spares and the time to affect a repair a factor in assessment of system performance. Electronically scanned radars, mitigate this in active designs where power is distributed across the array face and there is no single point of failure. However, the price paid is considerably higher systems costs. Both are active sensors and hence are more vulnerable to physical and electronic attack than passive radar in which the receive only character of the system makes it largely undetectable and much less susceptible to attack. Typically, passive radar will use multiple transmitters and so there is a degree, albeit coarsely, of graceful degradation unless all transmitters are switched off simultaneously. Equally, the potential for setting up a "friendly" transmitter can be factored into the concept design and hence assessment of overall availability of the capability. Once again, the complex interactions between different sensor capabilities makes the problem of selecting the most appropriate sensing solution much more involved than it might seem at first sight. Nevertheless, if there is a careful consideration of all the key factors then it should be possible, collectively, to do this in a form that articulates overall system availability. Only once this is done can a sensible comparison of sensor system options be made that are on the same evaluation basis.

3.4 Information Quality

Information quality goes to the heart of the performance of any sensor system, determining to a great extent the ensuing military capability. In general, the quality of information that can be provided by a radar system is primarily related to signal to noise (or clutter/interference) ratio SNR. Without adequate SNR targets cannot be detected reliably and hence tracking and classification are inherently compromised.

A common comment also made about passive radar is that the performance in relation to detection as well as parameter estimation is either variable and/or unreliable in part due to the system geometry and in part due parameters comprising the passive radar being beyond the control of the designer.

Firstly, it should be pointed out that no radar system, active or passive, has a performance that can be said to be constant and reliable. The reason for this is simple, the performance of all radar systems is dependent on the scenario being viewed and the conditions prevalent at the time of that viewing. It is a myth that monostatic active radars have consistent and predictable performance. Target detection is usually expressed in terms of probabilities of detection and false alarm. These are averages and in practise there may be significant deviations from the stated values. In fact, probabilistic radar performance is rarely measured and instead computations based upon models for the target and background are often used for performance prediction. Inevitably, these models have simplifying assumptions that are not fully representative of all conditions likely to be encountered and hence only give indicative performance levels. These predictions may be part backed-up by measurements but gathering enough data to be both statistically significant and representative of a broad set of scenarios is unrealistic. Nevertheless, a mixture of modelling and full-scale testing has been established as an imperfect but acceptable means of evaluating and predicting monostatic radar performance. Even here, new methodologies such as cognitive signal processing and intelligent resource management are challenging these accepted norms. In regards of passive radar, assessment of performance can still be done on the same basis to ensure compliance with the requirement. A mixture of modelling and measurement puts assessment on the same footing as for any active radar system. However, for passive radar this is a bit more challenging as reliable, well-proven, models for targets and clutter under bistatic conditions are not readily available. Additionally, there are a huge range of bistatic geometries that, ideally, would have to be considered. These are somewhat reduced for a specific application such as air space surveillance. However, the comparatively small amount of research and development applied to passive radar means that there isn't the same wealth of experience to draw on and this naturally leads to a greater degree of uncertainty as to the performance that will be achieved in operational scenarios. Indeed, passive radar data is extremely sparse and this is something of a real obstacle in terms of passive radar performance assessment and prediction and ought to be an area targeted for further immediate research. The scant data that does exists could suggest the bistatic RCS of targets to be generally lower than the equivalent monostatic RCS [6]. Whether or not this is the case for stealth targets is largely unknown. If the bistatic RCS is lower, it will reduce detection range. Equally, there is almost no evidence to suggest that, for most geometries, the bistatic clutter is also reduced and this would aid detection performance. In general, the relative differences in target and clutter RCS as a function of geometry is an unknown. Knowledge of this will tell us much more about performance and performance variations. Also note that if the range requirement is satisfied by each type of radar, even though the performance may be inferior in any given case, that system is still a valid candidate as it may have other overriding attributes. Overall, the paucity of data driven models does highlight the need to back up any claims with evidence provided by measurements and such measurements need to be sufficiently representative of the expected range of operational scenarios including geometries. In practise, this is difficult to achieve in a form that can be fully relied upon.

For other performance assessment aspects similar issues arise sometimes with more subtle effects. For example, a minimum detectable velocity (MDV) might form part of a requirement. In all radars, this is determined by a combination of radar design parameters, especially the selection of frequency, Doppler resolution (set by the time on target). MDV is by limited clutter spectral spreading, and is also a function of the environment being interrogated together with likely important target velocities (radial/bistatic bisector). Here, performance is a little easier to compute (notwithstanding that some simplifying assumptions still apply) and both active designs and passive designs will have different advantages and disadvantages. For example, in active radar that has a given frequency of transmission, the dwell time will determine Doppler resolution and this will be constrained by the need to scan the desired search volume. In passive radar operating in a staring mode, no such limits apply but the frequency of transmission being exploited will be fixed. Typically, passive radar will operate at lower frequencies than active radar. If so this will mean that integration times via an FFT may have to be longer by the ratio of the active radar frequency to the passive radar frequency to achieve the same MDV. The Doppler spreading of stationary clutter (wind blown vegetation/trees etc.) is likely to be less at lower frequencies. Overall, it can be concluded that there are multiple ways to satisfy a requirement such as MDV but with potential implications for other aspects of performance. Of course, all must be assessed collectively and not individually. Again, measurements to support modelling results are critical to ensure sufficient evidence for reliable assessment and predictions.

Location accuracies can be stated in terms of 3-D positional errors, using such descriptors as circular error probabilities (CEP) or similar variants. The ways in which positional information is extracted from echoes in active and passive radar can be very different and, potentially, this leads to a more complex and less clear-cut means of assessment. In active monostatic radar well-known techniques such as monopulse are used to more accurately estimate angular position and early-late range gating is used to more accurately estimate range. Passive radar can and does use similar techniques. Somewhat surprisingly, though, all current systems tend to use small circular antennas comprising of just a few (8-16) elements. This means that beamwidths are correspondingly large, which can adversely impact positional accuracy (as well as detection range and resolution of ambiguities). However, use of multiple transmitters and/or receivers can redress this. Clutter is a function of spatial resolution and hence can also be adversely accentuated with larger beamwidths. By and large, there is relatively little literature on passive radar antenna design and most current examples are variants on a small circular array concept. There is no reason not to use larger antennas to improve angular resolution and hence location accuracy more directly and also reduce clutter. Larger antennas are also a way to overcome reduced sensitivity to long-range high-altitude targets by designing more receive gain into the system where the illuminators of opportunity have reduced gain.

Overall, as before, it is a question of designing to meet requirements and assessing the advantages and disadvantages of different solution options and the way each can satisfy differing aspects of a requirement. In this regard there is no issue as to whether or not the radar is passive or active, monostatic or bistatic.

3.5 Other Requirements

There are, of course myriads of other requirements that must be considered in procuring an operational surveillance system. Some, as suggested earlier, push a passive radar solution more to the fore. For example, if there is a need to be covert then bistatic or multistatic geometries have clear advantages. However, this needs to be explored at a much more detailed level than simply saying separation of transmitter from receiver makes the system covert, undiscoverable and hence able to offer a special level of capability. Firstly, the requirements need to be carefully constructed so that the right military advantages are accrued. For example, it might be critically important that a weapons system can engage before a hostile jammer becomes effective rather than to avoid one own transmission being detected at all. This may or may not tilt the balance back to an active solution. The key point is that it is detailed modelling, perhaps through operations research and wargaming, that these aspects of requirement can be evaluated in terms of military benefit and then interpreted so that sensor system specifications can be developed appropriately.

4.0 PASSIVE RADAR ADOPTION

Passive radar has been spoken of openly in the press as a potential $10 billion business for over ten years. The realisation of this potential is still to happen and there is an open question as when and even if it will really occur. Passive radar is, to quite a high extent, a technology that has been pushed by technologists rather than pulled by users especially via clear understanding of performance, capabilities against well matured military requirements. There is a wealth of research, however, much of this presents either novel passive radar concepts using new illuminators of opportunity or use existing concepts to examine new applications. There is much less research into areas identified as lacking compared to monostatic radar or addressing possible weaknesses of the concept. This broadening of research has, perhaps, been at the expense of forward progress in key areas or only now is it becoming clear that the real-world advantages of passive radar need more extensive evaluation and testing and in a more operational like form.

Further, the degree to which all aspects of passive radar performance are understood, especially in relation to target and clutter models, inevitably raises a question mark over passive radar that doesn't apply to the same degree to monostatic radar. This puts passive radar at a disadvantage although, that is not to say that it is a negative aspect of performance. It is more that aspects of performance are not as assured because of the lack of real-world evidence that exists more readily in the case of active radar. Naturally, though, this makes potential customers for passive radars uneasy and it should leave the purveyors of passive radars, who cannot furnish such evidence, also uneasy. A direct consequence will be a much slower take-up of the technology as any mistrust needs to be eradicated and the requisite levels of customer confidence raised.

There are other issues that also may be inhibiting the adoption of passive radar technology. There are systems that have been developed by industry and are offered as passive radar products. However, these systems haven't really been developed to meet a specific requirement, and have their roots in technology demonstration rather than genuine capability demonstration. A specific example which best highlights this is the radar element of civilian air traffic management (ATM). ATM radars have to comply with very specific standards which stipulate aspects of performance. Eurocontrol has developed specifications that must be met by an air surveillance radar system for 3 and 5 nm separations [7]. These are detailed and, although they have their roots in air defence radars developed in the 1940s, have been modified to be more capability rather than solution based. In principle, there seems no real obstacle to passive radar satisfying all of these criteria. However, the proof must still be offered in the form of acceptable evidence. Indeed, it may also imply a different design of passive radar system to those currently available.

Lastly, the slow take-up of passive radar for military air space surveillance may also be a function of the timing of need combined with insufficient maturity of the technology at a whole system level. However, given the widening range of targets and trajectory types (stealth, UAVs, non-ballistic missiles etc.) that will stretch current surveillance equipment to beyond their design capabilities, military surveillance, requirements will have to evolve accordingly. Equally, this widening range of targets, with operations in multiple environments, may well require an air space surveillance capability that is more flexible and composed of a variety of sensors with differing yet complementary capabilities. In other words, simply considering a single sensor solution is unlikely to be a very satisfactory way to satisfy future requirements. A sensor mix that may or may not include passive radar, may well be the likely outcome. However, as stressed in this paper, the requirements should be based in military needs and priorities, so that the solution space can be explored independently and the most suitable, cost-effective sensing solution derived.

5.0 CONCLUSIONS

In conclusion, it can be seen that, whether or not it is a single sensor solution or part of a portfolio of sensors, passive radar should be treated no differently to active radar. In general, this can be achieved provided requirements are carefully constructed to be military capability based so that solutions options can be constructed and assessed on a common basis against a CONOPS driven requirement. It will allow all candidate solutions to be compared so that their advantages and disadvantages can be evaluated and the most overall, cost-effective solution selected on an informed, confident basis.

6.0 REFERENCES

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