# Evaluation of Radar Array Architectures for Low, Small and Slow Object Surveillance

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## *ABSTRACT*

*The proliferation of small unmanned aerial vehicles gives rise to new challenges in radar design. These objects are characterized by low values of radar cross section and often move very slowly, or even hover, at the background of clutter. This makes detecting them difficult, particularly for legacy systems that were not designed with this purpose. Specifically, to detect slow objects in clutter a long coherent processing interval is required in order to achieve sufficient Doppler resolution or to be able to distinguish moving parts (e.g. propellers) in the micro-Doppler spectrum. In legacy systems, modifying existing waveform to fulfil this requirement may result in excessive refresh times.*

*In this paper, we investigate system-level design options for designing radars whose role would be to perform surveillance of low, small and slow objects. The intended radar design should be cost-effective and, at the same time, have high performance in military environment characterized by congested and contested spectrum. We start our discussion with the issue of the array size and band then move on to the array architecture. We discuss pros and cons of the pencil beam and one- or two-dimensional beam cluster options. Mechanical scan in azimuth, multiple fixed arrays, and a cylindrical array are discussed as options to achieve omnidirectional coverage. We also investigate some novel techniques, such as MIMO and noise radar.*

## 1.0 INTRODUCTION

During recent conflicts the public opinion was repeatedly shocked with multiple videos showing small unmanned aerial vehicles (UAVs) harassing troops and equipment on the ground practically unchallenged. In some cases these videos showed UAVs flying over radars or attacking air defense assets, as if they were undetected. Even though many of these videos were obviously edited so as to reach a desired propaganda effect, they clearly show the increasing spread and importance of UAVs on the modern battlefield. Consequently, radar designers are now faced with an obligatory requirement of achieving good performance against this class of targets.

This paper is aimed to highlight the difficulties associated with detecting small UAVs and to present system-level design choices faced by a designer of a military radar that incorporates the requirement of LSS target detection. Note that the specifications of military radars are usually not only more complex, but also more difficult to satisfy due to the presence of challenging and possibly conflicting requirements, such as longer detection ranges, higher accuracies, shorter frame times, wider dynamic range of detected targets, wider range of admissible target velocities and maneuvers, or resistance to EW/jamming, to name just a few.

Due to length limits, this paper can only focus on a subset of this wide matter. It is organized as follows. In Section 2 we explain why detecting UAVs is challenging, particularly for legacy radar systems. This discussion shows the importance of long dwell times to achieving satisfactory probabilities of detection. Sections 3 and 4 form the main part of the paper. In Section 3, we discuss options related to the array size and band, scan mechanisms, and the array architecture. Section 4 takes a look at some novel techniques, such as MIMO (Multiple Input Multiple Output) and noise radar, and discuss their pros and cons with respect to LSS targets. Section 5 presents our conclusions.

## 2.0 THE CHALLENGE OF LOW, SLOW AND SMALL

Classical approach to radar system design primarily considers detection of relatively fast-moving targets, such as jet airplanes, cruise missiles, rockets, artillery and mortar (RAM) shells, while avoiding saturation with detections from "clutter". The term clutter refers all objects that are a source of unwanted radar echo. Typical sources of clutter include, among others, ground and sea surface, buildings, masts, power lines, precipitation in the form of rain or snow, road traffic, and birds.

Fundamental approaches to the problem of clutter rejection include constant false alarm rate (CFAR) circuits, clutter maps and Doppler filtering in the form of moving target indication (MTI) or of moving target detector (MTD) [1]. CFAR circuits are effective at preventing false detections form spatially large sources of radar echo (ground/sea/precipitation), while clutter maps can mask detections from discrete stationary or slowly moving scatterers such as masts, buildings or birds [2], [3]. MTI and MTD radars can achieve excellent rejection of clutter by exploiting the fact that majority of clutter sources have small radial velocities when compared to targets of interest. Briefly speaking, clutter can be rejected by forming a notch in the response of doppler filter (MTI processing) or filterbank (MTD processing) whose bandwidth matches the expected range of clutter Doppler shift. Additional means of clutter rejection could include dropping detections with small radar cross section (RCS) or preventing track formation on slow objects.

Rejecting clutter becomes considerably more challenging when the range of targets of interest consists not only of fast objects, but also includes the so called low, slow and small (LSS) targets. Primary examples of LSS objects are micro- and mini- UAVs and certain types of loitering munitions. As the name suggests, LSS objects fly slowly (say, < 30 m/s) at low altitudes and have small RCS (0.001 $m^2$ – 0.1 $m^2$) which makes their basic radar characteristics very similar to those of birds. According to [3], the probability density functions of bird RCS $\sigma$ and velocity $v$ are given by, respectively,

$$p(\sigma) = \frac{1}{\sqrt{2\pi} s\sigma} e^{-\frac{\left[\ln\left(\frac{\sigma}{\sigma_m}\right)\right]^2}{2s^2}}, \quad (1)$$

where $\sigma_m = 0.016$ $m^2$, $s = 1.4$, and

$$p(v) = \frac{1}{2v_0^3} v^2 e^{-\frac{v}{v_0}}, \quad (2)$$

where $v_0 = 5$ m/s.

From (1) and (2) one can conclude that 95% of birds have RCS smaller than 0.16 $m^2$ and fly with velocity in the range between 0 and 31.5 m/s, which clearly overlaps with LSS objects.

Consequently, a (legacy) radar designed to reject birds on the basis of radial velocity (and, possibly, RCS) will also suppress detections from LSS objects. On the other hand, a radar designed with a notch that admits slowly moving targets may face the problem of saturation with detections from birds. For example, assuming a bird density of 1 bird per square kilometer, there would be more than 1200 birds in the range of 20 km from a radar. To prevent this problem, the radar design should include means to differentiate valid targets from birds, which may take the form of e.g. microdoppler analysis or track behavior analysis [4], [5].

Another challenge arises when one considers the detection of targets that are hovering, or nearly hovering, at low altitude, i.e. at the background of ground clutter. To detect such targets, one is required to either to discriminate the echo of their body or moving parts (e.g. propellers) from the echo of the ground. In both cases, long time on target is beneficial. In the body detection case, increasing the time on target $T_o$ improves velocity resolution according to

$$\Delta v \sim \frac{c}{2T_o F}, \tag{3}$$

where $c$ denotes the speed of light and $F$ is the radar operating frequency. High velocity resolution (small $\Delta v$) allows one to separate the slowly-moving body from stationary ground (assuming that internal clutter motion and other system instabilities allow such separation – see e.g. [1], [6] for more details). In the case of moving parts, long time on target enables detection of rotor blade flashes or formation of helicopter rotor modulation (HERM) and/or micro-Doppler spectrum [7]. The associated high velocity resolution allows one to differentiate the features present in these spectra from clutter.

Note that upgrading an existing radar with the LSS target detection capability may be very difficult and require substantial tradeoffs. For example, increasing the time on target so as to allow detection of hovering targets could result in an increase of the frame time, i.e. the radar refresh period, beyond acceptable limits. Additionally, a tracking system might be unable to handle the increased number of detections caused by birds and require substantial redesign. Therefore, we conclude that a design of a modern radar should take the requirement of detecting LSS targets into account from the very start.

## 3.0 RADAR SYSTEM DESIGN FOR DETECTION OF LSS OBJECTS

### 3.1 Array Size and Band

The search radar equation, which plays a fundamental role in design of surveillance radars [1], states that, assuming fixed frame time and search sector, the detection range of the radar $R_{\text{det}}$ is proportional to the fourth root of the product of its average power $P_{av}$ and receive aperture $A_e$

$$R_{\text{det}} \propto \sqrt[4]{P_{av} A_e}. \tag{4}$$

In active electronically scanned array (AESA) radars the output power is proportional to $A_e$, which means that

$$R_{\text{det}} \propto \sqrt{A_e}. \tag{5}$$

Since the cost of building an AESA array is also roughly proportional to $A_e$, the radar cost comes as proportional to the square of the detection range. Given the task of providing surveillance along a border or a frontline, Eq. (5) favors the use of a number of smaller radar, rather than a single large radar. The use multiple smaller radars also brings benefits of avoiding the problem of radar horizon and “graceful degradation” in case of the radar network being physically attacked.

The dimensions of the AESA array aperture are not only major factor that affects its cost. The radar operating band comes as equally important in determining the total cost of the radar. Modern planar AESAs can incorporate more than 1000 transmit/receive (T/R) modules, each module being connected to one radiating element, typically located at the nodes of a rectangular or a triangular grid. Spacing between nodes is chosen by design to be close to half-wavelength in order to provide the ability to scan the antenna beam in a wide sector of angles. Thus the antenna dimensions $L$ are proportional to the radar signal wavelength $\lambda$ and requirements describing 3dB beamwidth of the antenna pattern

$$\theta_{3dB} \propto \frac{\lambda}{L}. \tag{6}$$

The large size of the array in relation to the radar operating frequency allows for a narrow beam and high directivity. Higher frequency allows the beam to be narrower, for a given antenna dimensions.

When designing AESA, in addition to the usual limitations, additional constraints related to the use of T/R modules must be taken into account. Usually T/R modules are placed behind radiating elements and their maximum size is limited by the size of an antenna element and distance between the array grid nodes. It means that when the frequency increases the space for T/R modules decreases due to array aperture decreasing. The space available for T/R modules and additional circuits, such as power supply, cooling, diagnostic and control is an issue that is solved by finding a balance between AESA performance, available power density on area unit, thermal management and economy of the system. Thus, T/R modules with high output power levels (hundreds of watts) are available at lower frequencies, while modules with lower output power (tens and single watts) are used in AESA operating at higher frequencies.

Low frequency operating band (eg. VHF/UHF, L) offering small atmospheric attenuation and ambient noise is commonly used by long range surveillance radars with large array dimensions that are necessary to achieve acceptable measurement accuracy and antenna gain. Usually the radar systems designed in this band are not highly mobile. They are transportable, or even designed to work stationary in fixed site. This operating band offers very good surveillance and early warning radar capabilities, however it is not used for precise target tracking and weapon cueing. While the low frequency bands are commonly thought of as providing good low observable (LO) target detection capabilities, it must be noted that they are somewhat impaired at detecting small UAVs because of to the mismatch of the wavelength and the size of the drone components [1], [8], as well as sensitivity to polarization alignment [8].

High frequency band (X, Ku) are used to design highly mobile radar systems or even systems operating on moving platforms. This band is characterized by relatively high atmospheric absorption losses, as well as rain and water vapor attenuation. In addition, ambient noise that affects radar performance is more noticeable at higher frequencies. The radar designed in this band are usually characterized by shorter detection range, which is not necessarily a problem for a drone surveillance radar. High measurement accuracy is achievable using relatively small array antenna, to the point that precise target tracking and weapon cueing or fire control is feasible.

Middle frequency bands (S, C) provide good compromise, offering advantages of above bandwidths. S and C bands are commonly used by weapon locating or ground based air defense systems for immediate indication of threats, precise target tracking as well as weapon cueing or missile guidance. Compared to X and Ku bands, S and C bands are also characterized by easier management of Doppler ambiguities, which is an important issue if a wide range of target speeds is expected.

## 3.2 Scan Options and Array Architectures

A relatively cost effective option for large volume search is a radar design implementing rotating AESA array. Despite the costs of rotary joint and antenna drive, covering 360° in azimuth with this solution is relatively cheap and uses small volume of necessary apparatus that has low weight. On the other hand, this solution introduces a limitation on the refresh rate for the volume search, which is defined by the antenna rotating speed. Additionally, the time on target $T_o$ that the antenna beam spends in one direction depends on the 3dB beamwidth and the rotation speed $\omega$ of the antenna.

$$T_o \approx \frac{\theta_{3dB}}{\omega}. \tag{7}$$

As explained in Section 2, long time on target is highly desirable for LSS surveillance, which means that the rotating array approach is somewhat limited in this context – achieving a long time on target requires one to use a wide beam, a slow rate of rotation, or a combination of both.

A more expensive option to cover 360° in azimuth is a set of 3 or 4 separate planar AESA working independently. In practice, this solution may be treated as several separate radar systems, each covering respectively 120° or 90° sector in azimuth. It follows that the time required to search the 360° azimuth sector may be cut by the factor equal to number of sectors searched simultaneously. Alternatively, the time on target may be increased by the same factor, which should improve the radar's LSS detection capabilities. Additionally, this approach allows one to adjust the refreshment rates and the time on target for each of simultaneously performed tasks with great freedom.

A cylindrical AESA may be good alternative to rotating antenna solution or expensive and heavy set of planar antenna arrays. A cylindrical antenna array can electronically scan radar beam around 360° simultaneously covering required sector in elevation using scanned or stacked beams. This solution is somewhat similar to a rotating antenna, but changing antenna beam rotation speed (data refreshment rate) or freezing a beam on target is easily achievable without limitations introduced by mechanical devices (antenna drive).

Modern AESA radar may utilize different beams for performing different tasks, such as surveillance or tracking. Using switched pencil beams for surveillance is, generally, time consuming and may adversely affect other radar capabilities. Specifically, with this approach, there is a very strong conflict between angle estimation accuracy, which improves for narrow beams, and the time on target that – given constant refresh rate – shortens for narrow beams. It follows that the switched pencil beam is suitable for LSS surveillance only if neither high accuracy in angle nor short frame times are not required. Pencil beams are, on the other hand, highly effective solution for target tracking, because thy focus energy in the directions of interest, i.e. targets. It results in increased SNR, which improves detection range and angle estimation accuracy.

Scattering energy into several pencil beams formed in one or two dimensional cluster may be a very effective solution for a radar to omit some of its time and energy budget limitations so as to increase the time on target and improve LSS radar detection performance. It also helps to achieve multitask/multifunction capabilities, such as simultaneous search and track, moving and hovering target detection, target detection and recognition. In one approach, a cluster of pencil transmit and matching receive beams may be used. Another option is to form one wide beam for transmitting and a cluster of receiving pencil beams. Beam clusters are commonly used with both rotating and non-rotating AESA for detecting and tracking targets and to provide time savings in the radar time budget. In terms of LSS target detection, using some form of beam clustering seems essential, unless the requirements are really benign.

From the purely technical point of view, a two dimensional cluster it is the preferred approach for the LSS surveillance, because it will generally enable longer times on targets than when using one dimensional clusters. It is, unfortunately, a considerably more expensive approach than using a one dimensional cluster, which means that small radars are likely to opt for the latter. Interestingly, the rather common approach to surveillance radars that employs a rotating array, a cosecant-squared transmit beam, and several pencil receive beams stacked in elevation, suffers from the limitation of time on target given by (7), which makes it of limited use for LSS surveillance. A horizontally arranged cluster is, therefore, an option worth considering, particularly if the required elevation sector coverage is not too large.

Beamforming and control in an AESA array can be implemented either by using analog or digital approach. Analog beamforming uses a one- or two-dimensional antenna feed network that combines RF signals for receiving and splits the signal from centralized exciter for transmit. Amplifiers and phase shifters inside the T/R modules are designed to provide the required amplitude and phase distribution across the antenna aperture. The number of different antenna patterns that can be created is limited by the capabilities of the analog network. The quality of the pattern is determined by the quality of the high power microwave signals that excite the radiating elements in the array, which in turn depends on the manufacturing errors of the feed network and T/R modules.

Nowadays, digital beamforming is the dominant solution used for receiving, because of its obvious advantages. In this approach, the signals from the array outputs are first digitized and then coherently combined using suitable complex-valued weights. The weights used for beamforming may be changed on-the-fly, which gives great freedom in shaping the antenna receive patterns and opens additional possibilities, such as simultaneous formation of multiple receive beams that form clusters, adaptive beamforming, partial elimination of multipath effects, or using super resolution direction of arrival methods. A well designed digital beamforming array can achieve ultra-low levels of sidelobes provided that it was properly calibrated and that its design includes technical means to measure amplitude and phase distortions of the receiving channels that are required to update its calibration in response to e.g. aging and temperature drifts.

Digital beamforming comes in two flavors. The so-called fully digital, or element-level, approach requires one to digitize all of the RF signal that excite each of the radiating elements in the antenna array. This approach has the greatest capabilities, at the price of high complexity and cost. Generally, it is easier to implement fully digital beamforming at lower bands, because of the lower number of radiating elements and the greater spacing between them. Another option is the so-called hybrid digital beamforming, in which case the elements in the array are combined into subarrays using analog networks, and the digital beamformer works on the outputs of these subarrays. In this case, the number of subarrays, their size and positions at the antenna aperture affect the tradeoff between the array capabilities and complexity/cost. Note that the answer to the question which of the two approaches fits LSS surveillance is anything but obvious, and will ultimately depend on the requirements and economic limitations.

# 4.0 NOVEL TECHNIQUES

## 4.1 MIMO Radar

MIMO radar transmit multiple orthogonal waveforms from a number of transmit elements or subarrays (only the so-called collocated MIMO radars will be considered here). Each transmitted waveform originates from a different point in space and experiences a different phase shift on its way towards a target and back to the radar. The orthogonality of individual waveforms allows one to separate them at the receiver, extract the associated phase components, and form a so-called virtual coarray. The virtual coarray is in most cases larger in size than the physical array, which means that MIMO radar can potentially offer better accuracy of target angle estimation than a "classical", i.e. multiple input single output (MISO), radar. The word "potentially" refers to the fact that in MIMO radar energy is transmitted with small directivity (possibly omnidirectionally), which means that a single-pulse signal to noise ratio in MIMO radar might be small compared to MISO operation. Assuming that a search function is performed, one can solve this issue can by increasing the time on target so as to integrate more pulses coherently. That is, in the context of search function and LSS objects, this inherent characteristic of MIMO operation is not necessarily a problem, but actually – beneficial. We note however, that a MISO radar can achieve comparable time on target by using a spoiled transmit beam and a cluster of receive beams. In such a situation a MIMO radar still offers the advantage of better angular accuracy, although it is one more time stressed that this applies to the search function.

Another advantage of MIMO radar is its potentially better resistance to jamming due to the use of waveform diversity that is inherent with this technique, although MIMO radar is certainly not immune to it.

Unfortunately, the benefits of MIMO radar do come at a price. Obviously, MIMO radar requires a more complex exciter and feed, and the associated digital signal processing is considerably more computationally complex than in the MISO case. To achieve comparable accuracy, a classical radar design would simply increase the transmit power appropriately. It is somewhat unclear which approach is more cost effective, although in the future the balance may shift in favor of MIMO radar due to the advances in digitalization (e.g. a cheap fully digital T/R module with high enough output power output could be a breakthrough) and the growth of computing power available.

Other problems associated with MIMO radar are more fundamental in nature, however.

First, the transmit efficiency of a MIMO radar antenna is generally smaller than that of a classical design. This is due the existence of mutual coupling between transmit elements and due to the fact that MIMO waveforms often exhibit phase shifts close to $180°$, which results in the radiated energy being reflected back towards transmitters where it will be dissipated into heat. A MIMO radar with sparse transmit array made of widely separated sources will suffer less from this problem due to smaller level of mutual coupling. Note that such an array may require smaller level of integration, and therefore be less costly to build, although in this case it would be more difficult to revert back to the conventional MISO mode in case this is required (e.g. for performing the track function in case of a multifunction radar).

Second, in sharp contrast to classical MISO radars, where the design of the antenna and waveform are decoupled from each other (the antenna design governs the properties related to the angle domain and the waveform design governs the range/Doppler properties), in MIMO radars these aspects of the design are closely coupled. While it is true that this property can be seen as beneficial, because it provides the designers with more degrees of freedom, it also makes the overall design more difficult and error-prone. A poorly designed MIMO waveform can result in “unusual” phenomena, such as an error in estimating target Doppler causing an error in estimating its angle. Therefore, it is essential that specialists from antenna design and signal processing work very closely with each other and that each have a good understanding of how their actions affect another “side of the stick”.

Finally, the ambiguity function of a MIMO radar waveform necessarily has some rather undesirable properties whose severity increases with the number of orthogonal waveforms employed. One such property is the result related to the so-called “volume-clearance condition”. Consider a MISO radar that emits an infinite trail of pulses with pulse repetition frequency $PRF$. An unambiguous delay (which translates to unambiguous range) of that waveform equals $\tau_{\max} = 1/PRF$, while unambiguous Doppler is $f_{\max} = PRF$. The product $\tau_{\max} f_{\max}$ equals 1. For a MIMO radar this product will generally be smaller by a factor $K$. More formally, let

$$|\chi_K(\tau, f)|^2 = \sum_{i=1}^{K} \sum_{j=1}^{K} \left|\chi_{ij}(\tau, f)\right|^2, \tag{8}$$

where $\chi_{ij}(\tau, f)$ denotes the regular auto or cross ambiguity function of $i$-th and $j$-th waveform in the orthonormal waveform set. Denote by $A$ some set on the delay-Doppler plane and let

$$V_K(A) = \iint_A |\chi_K(\tau, f)|^2 d\tau df. \tag{9}$$

Then it holds that [9]

$$V_K(A) \geq \frac{K}{4} C(A) V_{K0}, \tag{10}$$

where $C(A)$ is the area of the set $A$ and $V_{K0}$ is the volume of the pulse of the MIMO ambiguity function $|\chi_K(\tau, f)|^2$ at the origin. The importance of this result should not be underestimated. Assuming that the set $A$ represents an area of uniform clutter in the delay-Doppler plane, the clutter power at the output of a matched filter processor is proportional to $V_K(A)$,

$$P_C \propto V_K(A). \tag{11}$$

A related property applies to MIMO phase coded (also referred to as code domain multiple access, CDMA) waveforms. For $K$ codes of length $N$ the peak autocorrelation $PACR$ and the peak cross correlation $PCCR$ are bounded by the following relationships [10]

$$PCCR \leq \frac{1}{2N-1} - \frac{2(N-1)}{(2N-1)(K-1)} PACR \qquad (12)$$
$$PACR \geq \frac{1}{N^2}$$
$$PCCR \geq \frac{1}{N^2}$$

In other words, there is a tradeoff between $PACR$, $PCCR$ – the higher the number of waveforms $K$, the more difficult it is to have both $PACR$ and $PCCR$ low. Considering Eq. (11), which shows that the levels of $PACR$ and $PCCR$ are related to the radar's susceptibility to clutter, the importance of (12) becomes clear [9], [11].

It follows from the above discussion that one can expect a MIMO radar to encounter larger difficulties managing ambiguity and clutter, which may be important in stressed designs. However, as small drone surveillance radars, particularly those with short range and operating in the mid-frequency bands, are likely not to run into this problem, MIMO radar is a promising technology that is worth exploring in this particular application.

## 4.2 Noise Radar

Noise radar is a radar that employs random (or pseudorandom) modulation of its transmitted waveform, which can be continuous wave or pulsed. In a pulsed noise radar (the CW case will not be discussed here due to severe problems with dynamic range that limit its detection range, see e.g. [12]), each pulse in a coherent pulse trail is typically modulated differently. This approach offers unique advantages, such as lack of ambiguity in range and Doppler and, perhaps more importantly in military applications, resistance to repeater jamming. Since a digital radio frequency memory (DRFM) jammer cannot predict the code applied to any pulse, it can only create false detections radar retroactively, i.e. at a range equal to or greater than its own range to the radar.

Noise radar is also a natural companion to MIMO radar. The random modulation applied to each pulse allows one to create waveforms with good orthogonality, particularly if long coherent processing intervals are employed, which – as we already argued – would be a normal situation in a MIMO radar or, more generally, a radar designed to detect LSS objects.

On the other hand, a noise radar requires different approach to canceling clutter than a classical radar. In noise radar, due to a different random modulation applied to each pulse, clutter has to be cancelled using adaptive filtering techniques [12]. The computational complexity of this operation is several orders of magnitude greater than for the classical Doppler filtering. Without it, however, the noise radar becomes crippled, because the range-Doppler sidelobes of the ambiguity function (so called noise floor) of the noise waveform mask nearby weaker targets. The problem of clutter cancellation becomes even more difficult if one takes into account cancelling not only ground, but also volume clutter, such as rain, snow, or chaff. Unlike ground clutter, which is focused around zero Doppler, volume clutter is Doppler spread, which means that an adaptive filter must cover an wide range of delays and Doppler shifts – an issue that results in a further increase of the already high computational complexity [13]. Out of the rain-snow-chaff trio, dealing with chaff is particularly important, because chaff can have high radar cross section that – if dispersed sufficiently close to the noise radar – could significantly rise its noise floor and mask targets of interest. Rain and snow are less of an issue, particularly at lower-frequency bands, due to the fact that their reflectivity drops sharply with frequency [1].

## 5.0 CONCLUSIONS

Reliable detection of low, small and slow objects is a challenging requirement faced by modern radars. Detecting such object, particularly if they are hovering, requires long coherent processing intervals, which can stress the radar time budged. We have outlined several approaches regarding radar array design that allow one to achieve long coherent processing intervals without increasing frame times excessively. We also gave a short discussion of MIMO and noise radars and their place in LSS object detection.

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