A new Sensor for the detection of low-flying small targets and small boats in a cluttered environment

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ABSTRACT TITLE

In the context of stabilisation operations within Joint Forces, modern Navies contribute to the protection of the sea lines of communication, strategic key positions as well as coastal and territorial waters. The most likely tasks are anti-terrorism operations, crisis management and conflict prevention. This includes the capabilities required to operate against and defend from asymmetric threats, e.g. low flying aircraft or small boats in heavily cluttered littoral environments.

With the TRS-3D/24, EADS has a radar sensor which is perfectly designed for the operational tasks in the above described environment. The concept of this new radar is described in this presentation.

1.0 INTRODUCTION

Key requirements for the sensors engaged in anti-terrorism operations, crisis management and conflict prevention are:

- Multi-Mission-Capability
- Littoral Capabilities
- Adaptation to new threats, e.g. from asymmetric scenarios
- Support of Integrated Weapon systems
- Reduced operational (ship) personnel

For the asymmetric scenarios, the main threat comprises low flying targets, e.g. paragliders or ultra-light aircraft, as well as small boats, all of which may operate in a terrorist role in the littoral environment. The characteristics of these kinds of targets are:

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- extremely low RCS
- a wide range of speed
- heights ranging from the surface to several hundred metres above the surface

In order for the sensor to detect these critical threats in time, the sensitivity in terms of dynamic range and clutter suppression, as well as the signal & data processing which must guarantee fast and reliable track initiation, must be addressed. The new radar sensor TRS-3D/24 is the answer to this challenge in the naval littoral environment, as well as for ground-based applications.

With the TRS-3D/24, EADS has a radar sensor which is perfectly designed for the operational tasks described above, in particular anti-terrorist asymmetric warfare. This radar, being the most recent development of the EADS TRS-3D family of surveillance and target acquisition radars, meets the requirements for operating in the littoral with strong and complex clutter environments. Furthermore, by employing technologies and algorithms from the other TRS-3D radars, the well known functionalities for air, coastal and sea surveillance, target acquisition and Gun Fire Support are maintained.

2.0 RADAR CONCEPT

The key requirements derived above drive the design, development and cost of all modern RADAR systems, including the TRS-3D/24. Especially the design aspects with respect to:

- Frequency selection
- Adequate waveforms
- Scanning strategy
- Radar Processor

have a strong influence on the final concept. Adequate values for these parameters are derived below.

2.1 Frequency Choice

The choice of C-Band as the operational frequency band for the TRS-3D/24 RADAR had been based on a trade-off analysis, in which the operational, economical, system and integration requirements were evaluated versus their influence on frequency selection. Apart from this trade-off, EADS has built up vast and successful experience in the past 25 years with C-Band in tactical radar for naval littoral and land-mobile applications.

A comparison of C-Band with lower frequency bands (e.g. S-Band, L-Band), which are also commonly used for these applications, shows advantages especially regarding the new type of threats as mentioned above.

- Equipment size and weight must be minimized for naval top mast installation as well as land-mobile radar systems. Here the compact design of the antenna as well as of the RF Front-End is supported by the choice of C-Band.

- The Doppler velocity resolution increases with increasing carrier frequency according to $\Delta f_d \sim v_r/\lambda$: This improvement will be roughly a factor of 2 for the case of a C-band versus S-band radar, assuming a fixed and given Doppler processing time. The target velocity accuracy improves accordingly.
- Higher frequencies enable finer angular resolution in azimuth and elevation for given antenna dimensions, and hence better angular separation in elevation and azimuth by a factor corresponding to the frequency.
- For surface targets, which can not be resolved from clutter by means of the Doppler effect, surface pulse waveforms with short pulse duration (high instantaneous bandwidth) have to be realised, in order to deliver acceptable Signal-to-Clutter ratios. These short pulses can be realised much easier at higher frequencies (lower relative bandwidth), taking into consideration the whole transmit and receive chain.
- Multipath and propagation effects effects: For low elevation angles, the direct target echo return interferes with the target echo return signal reflected from the sea surface, which may lead to a significant reduction of target signal energy at the radar received input. This effect clearly decreases with increasing frequency. The result of numerical analysis of this effect is depicted in Figure 1, where for C-band and S-band the Single Pulse Signal-to-Noise-Ratios are plotted for a typical target at low altitude.

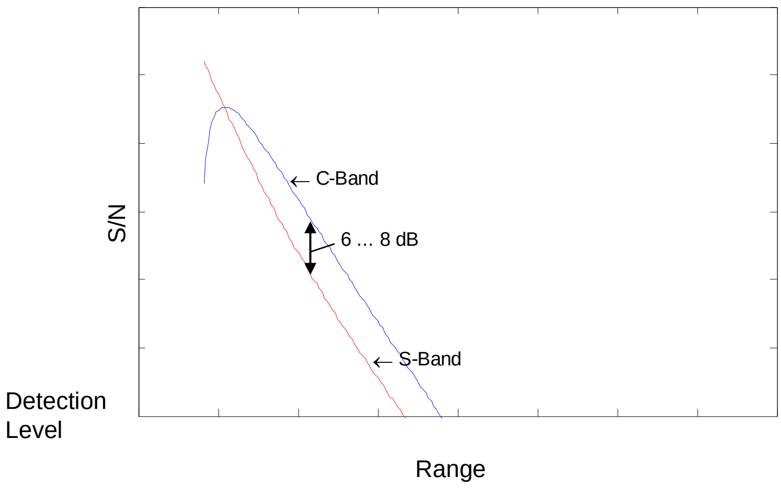

Figure 1: S/N for a standard target, standard atmosphere and altitude 5 m above water (Seastate 0). (Notch is due to multipath effects)

Taking into account atmospheric and clutter effects the choice of a lower frequency would be favoured Here C-band turns out to be a good compromise between S-band and X-band:

- Atmospheric attenuation and rain attenuation are generally quite moderate for C-band frequencies
- On the one hand sea and land clutter RCS increases with increasing frequency (C-band versus S-band). On the other hand however, this is more than compensated for by the advantage of smaller antenna beam widths (for a given antenna size), smaller range cells and smaller Doppler bin widths (for Doppler waveforms), which can be implemented with lower effort at higher

frequencies than for lower frequencies.

- For anomalous atmospheric propagation, no clear statement can be made if higher or lower frequency is more suited to cope with this condition. This is illustrated for two evaporation duct conditions in Figure 2, with duct heights 5 m and 30 m respectively. The S/N values and consequently the range performance depend strongly on the ratio of duct height and flight height, where for the one case C-band gives better results and for the other case S-band gives better results. Taking into account that lower duct heights have higher temporal probabilities than higher duct heights, C-band seems to have an operational advantage, as depicted in 3 of the graphs below.
- ECM conditions: Especially in littoral environments, jamming and interference become an increasing factor of negative influence:
  - For the same antenna size higher frequencies have smaller beams. This leads to better accuracy and resolution figures and hence to smaller sectors for main beam jamming.
  - The available radar frequency range increases with higher frequency. Hence a noise jammer has to spread the power over a larger bandwidth.
  - The coverage of EM radiation by other radars or by background radiation is much less in C-Band than in S-Band or X-Band

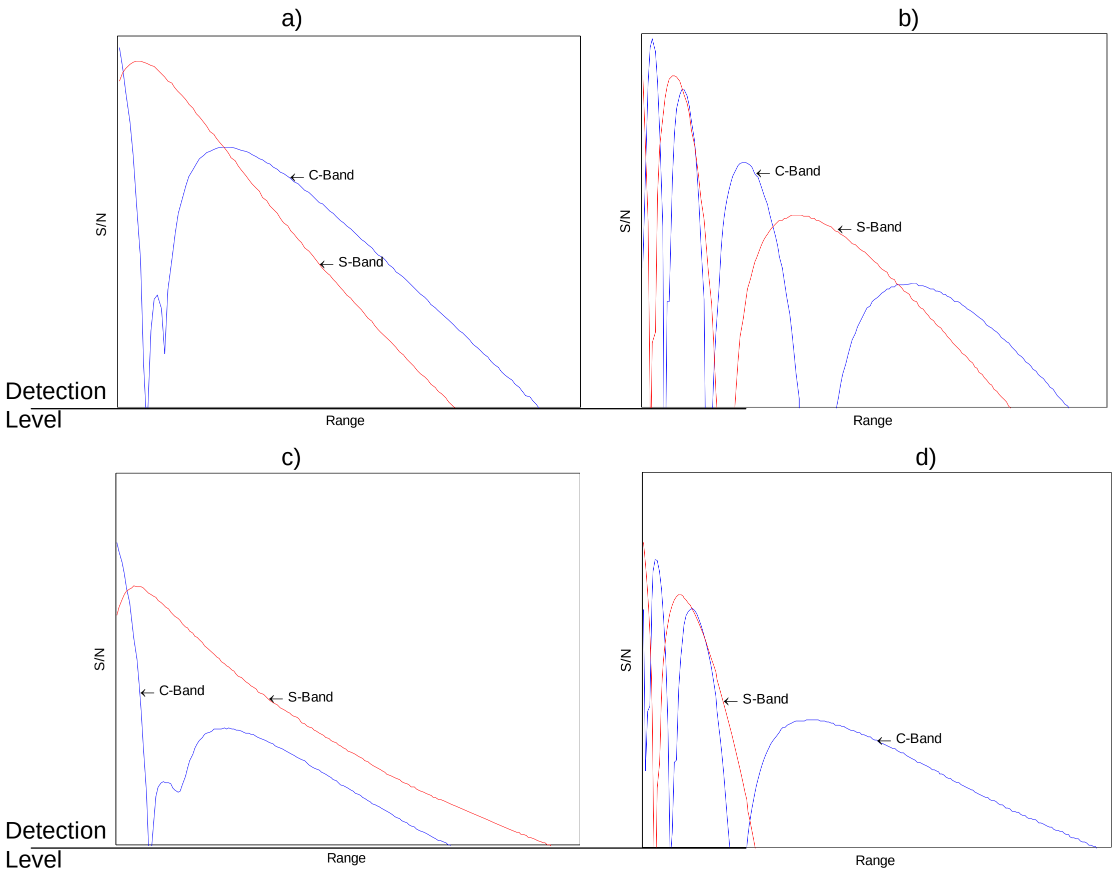

Figure 2: S/N for C-, S-band for different evaporation duct heights (EH) and altitude (FH) a) EH : 5 m, FH : 5m, **b)** EH : 5 m, FH : 15m, **c)** EH : 30 m, FH : 5m, **d)** EH : 30 m, FH : 15m

2.2 Scanning Strategy

Regarding the choice of the scanning strategy between sequential scanning with pencil beams and a stacked beam concept, the latter was selected due to the following reasons:

- The need for adequate dwell times to support Doppler processing and diversity gain on the target favours a stacked beam concept where the whole azimuth dwell time of the mechanically rotating antenna is available for target illumination (~9 ms for 2s rotation rate and 1.6°az beamwidth).
- Doppler waveforms optimized for detection and processing of moving targets can be realised for all elevation ranges.
- Highest possible elevation resolution is achieved by simultaneously forming "n" receive beams with highest possible elevation and azimuth resolution:
  - Especially for the lowest beams the stacked beam concept allows the implementation of monopulse and thus accuracies of a few percent of the beamwidth can be obtained.
  - With sequential beams, the amplitudes in adjacent beams at different times (and sometimes at different frequencies) are compared, and larger errors must be expected.
- Track continuity of targets moving between elevation beam positions is easier to realise with a stacked beam radar
- The increased number of receivers for the stacked beam concept reduces the requirements on dynamic range for the individual receiver compared to a single channel version

The stacked beam in TRS-3D/24 is characterised by using the TRS-3D antenna concept (24 identical radiator rows in the horizontal direction) but with individual receivers for each row. Beam-forming on receive is performed by weighted combination of the receiver outputs (digital beam-forming). The digital beam-forming (DBF) allows the parallel processing of different beams and adaptive beam-forming in elevation.

The transmit beam for illumination in elevation is formed by the use of electronically controlled phase shifters. The resulting transmit diagram and the DBF on receive allows adaptation of the scanning strategy to special scenarios.

2.3 Waveforms

Vast experience of TRS-3D operation in the littoral have proven that dedicated processing for sea and air targets, respectively, is necessary to deal with the demanding threat and clutter conditions. The concept of TRS-3D/24 makes use of the gained experience and consequently uses a waveform concept which comprises specific waveforms for air and sea targets for optimum detection performance.

The sometimes conflicting detection requirements for the high speed low flying targets and the small sea targets in clutter, lead to waveforms that provide adequate Doppler filtering with high signal-to-clutter improvement for the air targets and high signal bandwidth with high rotation rates for the surface targets. An attractive compromise resulting in one common waveform is achieved, sequentially covering the regions for these two target types to ensure stable detection and tracking. A typical order in time of such waveforms is depicted in Figure 3.

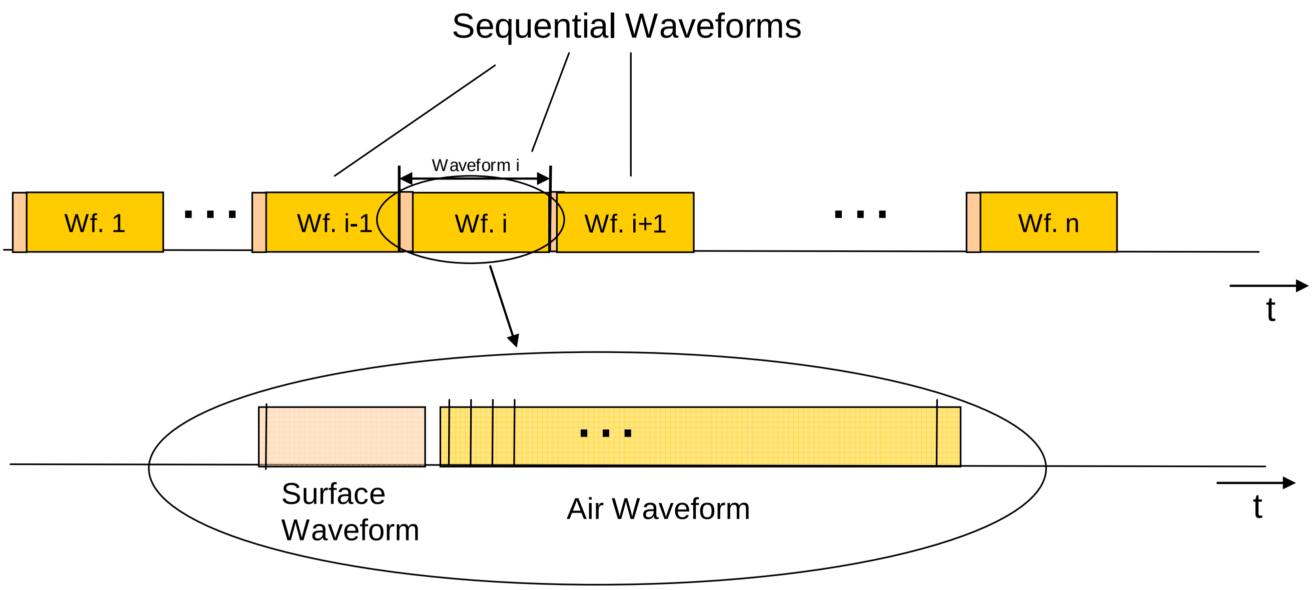

Figure 3 : Waveform Structure

2.3.1 Air Target Waveform

The separation of air targets from stationary clutter and slow moving targets by use of the Doppler spectrum is a well known process applied in Doppler radars for a long time. This process can be applied as far as the target velocities are within the unambiguous Doppler range of the radar. The unambiguou s Doppler (f_{Dua}) is described by the Pulse Repetition Frequency (PRF)

$$f_{Dua} = \pm PRF/2$$

or in terms of radial velocities

$$v_{ua} = \pm f_{Dua} * \lambda / 2 = \pm PRF * \lambda / 4$$

taking into account the measurement of incoming and outgoing targets.

The velocities of the high speed air targets to be detected (> 1000 m/s) lead directly to a High PRF design if unambiguous Doppler measurement is to be maintained. The High PRF waveform on the other hand means a strong folding-over in range. For example, designing a C-Band radar for a maximum speed of ±1000 m/s with a High PRF solution results in a PRF of 80 KHz corresponding to an unambiguous range of less than 2 km. This high folding-over in range would lead to extreme requirements in clutter improvement, which are hard to realise with today's available technology.

The waveform design with a range unambiguous waveform on the other hand leads to strong folding-over of the of the clutter spectrum at short ranges, which will cover the small targets or result in increased false alarms.

A compromise between these two types of waveform, namely high PRF for unambiguous Doppler measurements or low PRF for unambiguous range measurements, is the Medium PRF (MPRF) waveform allowing slight folding-over in range and in Doppler. The MPRF waveform allows the detection of fast small targets, according to the power budget of the radar, whilst still having the possibility of extracting them from clutter by the use of Doppler measurements. The ambiguity deconvolution of higher velocities and longer ranges can be performed by appropriate staggering of the PRF for successive coherent bursts of pulses..

2.3.2 Surface Target Waveform

The detection of sea targets in clutter by using non-coherent waveforms is a standard process used in naval radar systems. In TRS-3D/24 the non-coherent processing for sea target detection is supported by a high bandwidth waveform. This high bandwidth, allowing range resolutions in the order of small target dimensions, reduces clutter in the resolution cell to the minimum possible values. By using the well-proven procedures for sea target extraction from the TRS-3D radars, the detection of small sea targets is made possible.

The use of both waveforms in the data processing results in a reduction of false alarms and in short acquisition times for low-flying targets.

2.3 Radar Processing

Radar Processing comprises

- Elevation Beam-forming
- Signal Processing and Plot Extraction
- Tracking

applied to the input data. The individual steps are performed in the Radar Processing Chain which allows interactions between the individual processing steps. The interactions comprise

- information conserving filter processes
- track based control of processing resources

In the information-conserving filter process, the limitation of data transfer to the communication bandwidth between the processing units is overcome. Target information or information about disturbed areas are available throughout the complete processing chain. The necessary data can be requested from the processing elements.

The track based control of processing resources includes the the tracker requesting information about specific data, such as areas containing manoeuvring targets in clutter. The Doppler processing analyses these special areas using advanced detection algorithms, e.g. advanced clutter estimation.

3. SUMMARY

The requirements of many Navies to operate more and more within the littoral, subjects all naval radar systems to stronger and more complex clutter environments than was typical in the past. At the same time, radar cross sections of threatening targets are being reduced dramatically, putting more stringent demands on the technology of radar systems to be able to reliably detect and track such targets in the presence of very high clutter levels. These considerations led to the development of the TRS-3D/24, as the most recent member of the C-Band family.

The TRS-3D/24 employs many state-of-the-art technologies and processing algorithms, while at the same time utilizing proven concepts that have been demonstrated worldwide within the TRS-3D family to provide excellent capabilities in the littoral, from the Norwegian fjords, through the Baltic region to the Straits of Malacca.

EADS has decades of experience with its family of C-Band radars. This band offers an excellent compromise between good long-range surveillance performance for the compilation of recognised air and sea pictures, as well as solid track formation for hand-off to weapon systems, making the choice of C-Band as an operating frequency a logical one. The high measurement accuracy in bearing and elevation, given the size of the antenna aperture, contributes to the strong tracking performance and rejection of clutter plots. On the other hand, clutter levels and atmospheric effects are not as troublesome as they are with higher frequencies (X-Band), while the performance against critical low-flying threats is better than S-Band radars having the same free space performance. The latter applies to standard atmospheric conditions, as well as for typical ducting conditions.

To eliminate the need for a separate radar for sea surveillance, TRS-3D radars have always had coherent Pulse Doppler MTD (Moving Target Detection) filter bank processing for air target detection, and they have also included a non-coherent sea target channel to give smaller naval vessels a single radar solution. The TRS-3D/24 also includes both a coherent air target channel, as well as a parallel sea target channel, again providing a single radar solution for a naval vessel. Unlike the earlier generation TRS-3D radars that use a common waveform for sea and air target detection, the TRS-3D/24 uses a separate optimised high-resolution pulse for enhanced detection of small sea targets in clutter. Separating this pulse from the air channel permits the use of methods such as pulse-to-pulse frequency and PRI agility, methods that have proven their effectiveness for sea target detection.