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François Le Chevalier, Marc Montecot, Yves Doisy, Franck Letestu, Pascal
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STAP developments in Thales

François Le Chevalier^{#1}, Marc Montecot[#], Yves Doisy^{*}, Franck Letestu⁺, Pascal Chevalier^a

[#]Thales Aerospace Division, France

¹francois.lechevalier@fr.thalesgroup.com

^{*}Thales Underwater Systems, France

⁺Thales Avionics, France

^aThales Communications, France

Abstract— Space-Time Adaptive Processing (STAP) has been shown to provide significant improvements in many different application areas [1]. Though similar in principle, those applications exhibit specificities, related for example to the characteristics of the antenna arrays and to the statistical properties of the involved signals. In this communication, different examples of applications of Space-Time Adaptive Processing (STAP), currently being studied or developed in Thales, are reviewed, and some areas for future research are outlined. The following applications are considered (without exhaustivity): airborne surveillance radars, airborne combat radars, radio communications, satellite navigation, and underwater sonar systems.

I. INTRODUCTION

Taking advantage of multidimensional distribution of disturbances, Space-Time Adaptive Processing (STAP) improves the performance of sensors, at a price (computing power) which becomes acceptable in many application areas. In this paper, we will overview different applications currently developed in Thales and analyse shortly their specificities, in order to outline the variations of algorithms and the required efforts in research.

The following applications will be considered: airborne surveillance radars, airborne combat radars, radio communications, satellite navigation, and underwater sonar systems. This coverage is by no way exhaustive, since applications to surface radars antijamming, or to RF seekers, could also be mentioned, for example.

II. STAP FOR AIRBORNE RADARS

Space-Time Adaptive Processing of airborne radar signals is required in two typical situations of operational interest :

1-Detection, localisation, identification of moving ground targets: the best known application of STAP processing, where the main objective is to improve the minimum detectable velocity;

2-Detection of low observable air targets: when attempting to detect low-observable air targets from airborne platforms, the sidelobes of the antenna diagram often limit the performance. Mitigating sidelobes effect through STAP processing is therefore required, and the performance of this processing technique will define the overall detection performance of the system;

For the first application, previous experience with CFAR detection in adaptive ground surveillance radars (where the number of targets is strong, thus impairing the techniques using reference data in adjacent range gates) strongly points towards techniques based on exclusive use of the range gate

under test for threshold estimation: adaptive techniques “with no noise-only reference”, i.e. using only the samples received in the cell under test.

This approach [2] consists in looking for the filter minimizing the overall output energy, under a constraint of unity gain in the direction/Doppler of interest. This results in the well-known Capon filter, where the estimation of the covariance matrix R in the range gate under test is performed through temporal averaging (effective for STAP with limited number of channels).

Beside similarities in the expressions, the main difference between the two approaches: “no noise-only reference” (also called “single data set”), and “noise-only reference” is that the second one cancels the noise (based on the estimation of the noise covariance matrix from adjacent range gates), whereas the first one merely represents signal+noise (since it has no information discriminating signal from noise). An illustration with real measurements has been presented in [4].

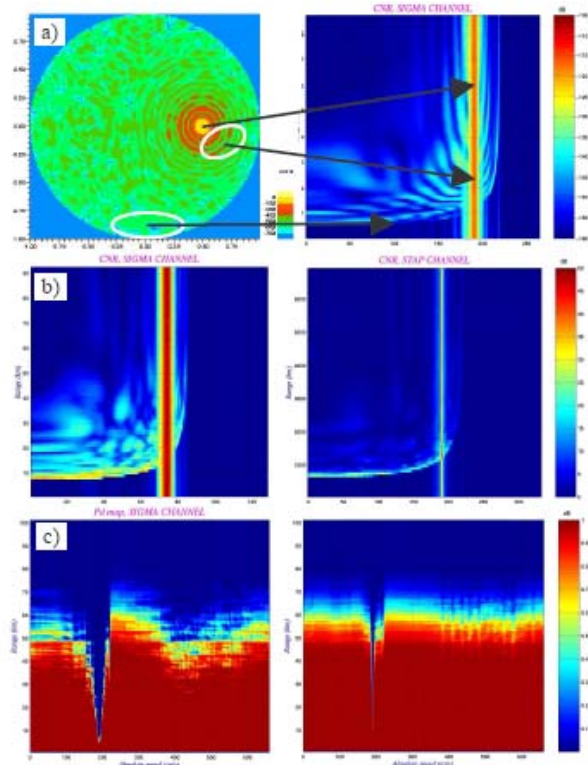


Fig. 1: a) Air / Air problem of STAP

b) Clutter Range-Doppler map without (left) and with STAP (right)
c) Probability Detection Map without (left) and with STAP (right)

For the second application (air to air) application, where sidelobe reduction is the objective, a post-doppler filter may be preferred in order to minimize the number of degrees of freedom (the time filter would require too many taps). A post doppler filtering pre Doppler training approach has been suggested as a good candidate [3], simulated and tested during flight trials within the AMSAR program. The simulated results in realistic conditions, Fig. 1, show clear improvements for both detection of targets in cross-sector near the main clutter beam, and detection of targets in regions polluted by the clutter returns from sidelobes.

III. STAP FOR COMMUNICATIONS SYSTEMS

Performance of most of wireless communications systems are limited by both propagation multipaths and interference. It is in particular the case for mobile cellular radiocommunications systems in urban areas for which propagation multipaths are mainly due to both reflection of waves on buildings and scattering effects in the neighbourhood of the reception antenna. It is also the case for long range HF ionospheric links where multipaths are due to the reflection of waves on the ionosphere layers. Furthermore interference are directly related to the frequency reuse concept in cellular systems and to the high spectral congestion of the HF band.

Destructive combinations of multipaths may generate the cancelling of the signal over the whole reception bandwidth, also called flat fading effect. Moreover, when the delay spread of the propagation channel becomes greater than the symbol duration, frequency selective fading and Inter symbol Interference (ISI), typical of HF ionospheric links for example, also occur at reception, which contributes to degrade the performance. Finally the presence of interference may strongly increase the Bit Error Rate (BER) after demodulation or may even prevent from demodulating the useful signal.

Flat fading may be mitigated by exploiting some diversity techniques. Temporal diversity, through error correcting codes and interleaving, is systematically used in radiocommunications. Frequency diversity, through Frequency Hopping (FH) or Direct Sequence Spread Spectrum (DS-SS) techniques exploitation or Orthogonal Frequency Digital Multiplex (OFDM) waveforms, are also frequently used in radiocommunications. Space and/or polarization diversity, in addition to the previous ones, through the use of sufficiently spaced multiple antennas at transmission and/or at reception, may strongly contribute to mitigate flat fading effects. For single carrier waveforms, selective fading requires some channel equalization at reception whereas for multi-carrier or OFDM waveforms, a processing in the frequency domain is required. In both cases, the use of the spatial dimension, in addition to the temporal or frequency one, may strongly improve the performance and may even allow the exploitation of an additional diversity corresponding to the multipaths diversity. Finally, even if techniques such as coding, FH or DSSS may increase the robustness of the link with respect to the presence of

interferences, they do not permit to completely reject the latter contrary to adaptive antenna processing.

For the previous reasons, Space-Time Adaptive Processing (STAP), aiming at jointly mitigating interference and both flat and selective fadings, has been developed these two last decades for wireless communications [5] and has given rise to the concept of Spatio-Temporal Modem. The most powerful ST modems are implemented from a training sequence inserted in each burst or frame of the link. This training sequence allows both the synchronization of the link and the multiantenna propagation channel estimation required to perform a coherent demodulation. These training sequence based ST modems are called informed ST modems contrary to the so-called blind ST modems whose implementation does not require any training sequence. Among the available informed ST modems, those developed by Thales [6] [7] present a very good compromise between performances and complexity, even for short training sequences of a few tenth of symbols. The ST modem presented in [6], whose functional scheme is depicted at Fig. 2, is even operational for the metrology of GSM cellular networks.

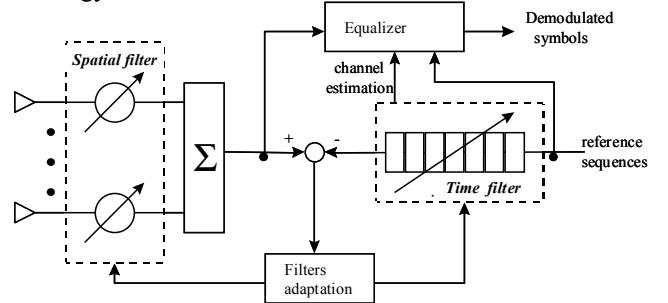


Fig. 2 Functional scheme structure of the ST modem [6]

Due to their effectiveness to mitigate both fading and interference, ST modems are at the heart of the development of next modems generation for many applications in radiocommunications

IV. STAP FOR SATELLITE NAVIGATION

The very low level of signals received from Global Navigation Satellite Systems (GNSS) means intrinsic vulnerability to interfering signals, which has to be mitigated through appropriate signal processing. Indeed, adaptive antenna techniques have been devised for enhanced reception in adverse environments (e.g. strong interferences, multipath). The use of adaptive antenna techniques is especially of interest in safety-critical GNSS applications, such as precise airplane landing or in-flight operation of UAVs.

Because of size and weight limitations imposed to the antenna array in potential applications, the most realistic array configurations have only few elements - typically 3 - 7. For such configurations, pure spatial-domain array processing only provides a low number of degrees of freedom for nulling-out the interferers and multipath, which may prove insufficient in harsh environments. The available number of degrees of freedom can then be increased by combining spatial and temporal array processing (STAP) algorithms [9].

In STAP structures, each antenna is followed by a tapped delay line structure used to realise an adaptive time-domain filter for shaping the antenna response in frequency domain and adjusting the signal group delays. The additional degrees of freedom provided by the time-domain filters enable to mitigate larger number of interference signals (compared to spatial-only processing) through quasi-optimal processing of broadband signals, especially for narrowband jammers which are effectively nulled-out in the frequency domain.

Depending on the algorithm, improvements of signal to noise ratios can also be obtained through beamforming, focusing the antenna array on the actual satellites directions.

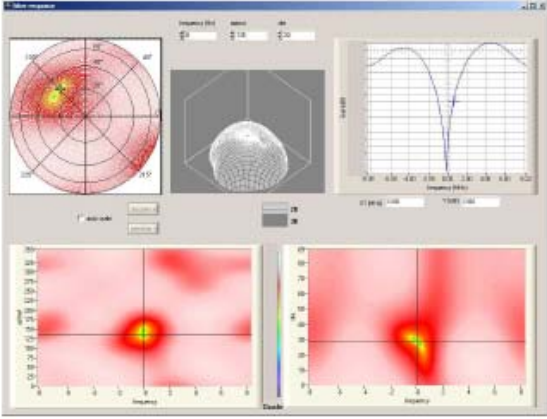


Fig. 3 Space-time response, 1 CW interference 135° azimuth, 30° site, 0MHz). Upper Left: antenna pattern at 0MHz; Upper Right: Spectral filtering in interference direction; Lower Left (resp. Right): Rejection at fixed site (resp. fixed azimuth)



Fig. 4 7-element antenna array and associated electronics

It has been noted that special criteria are required for application of STAP to GNSS system: post correlation signal to noise ratio should be maximised [8] (thus taking advantage of the increased filtering capacity provided by correlation) or positioning accuracy [10]. Moreover, for differential GPS applications, it is also necessary to accurately control the equivalent phase center of the antenna [11].

Some examples of results are given on Fig. 3, while associated electronics are presented on Fig. 4.

V. STAP FOR UNDERWATER SYSTEMS

The detection of slowly moving target in a strong backscattering background (reverberation for sonar, similar to clutter for radar) is a challenge to Surface Ship or Submarine Sonars communities. In this paper, recent advances obtained in the areas of adaptive beam-forming will be described, and the constraints in terms of stationarity and estimation duration

for the covariance matrix will be outlined. These constraints are addressed by reducing the number of degrees of freedom, usually using beam space adaptive beamforming. Finally, results on reverberation reduction obtained on a towed array sonar in CW mode will be presented.

Mono-static active sonar is generally operated with a pulse repetition rate (or ping rate) equal or larger than the round trip travel of sound to the maximum range. They are unambiguous in range because otherwise, the reverberation induced by the latest transmitted signal would mask the longer ranges. For active sonars operated from a moving platform such as a surface ship, waveform design is driven by the coherence time which sets a limit on the duration over which the signal can be processed coherently at reception without losses in the replica correlation process. The main effects limiting the coherence time are usually platform motions induced by the surface of the sea, which produce accelerations affecting the signal both at transmission and reception. This duration depends on sea state, frequency of operation, type of sonar (Hull Mounted Sonars are more affected than Variable Depth Sonars) and to a certain extent on pulse type. It ranges typically from 1s to 10 s. On an other hand, the detection ranges in active surveillance are typically between a 10 km to and 100 km, which correspond to a round trip travel time ranging from 13s to 130s: unlike the Radar case, this travel time is larger than the coherence time, and prevents the coherent exploitation of successive pings (ie pulses).

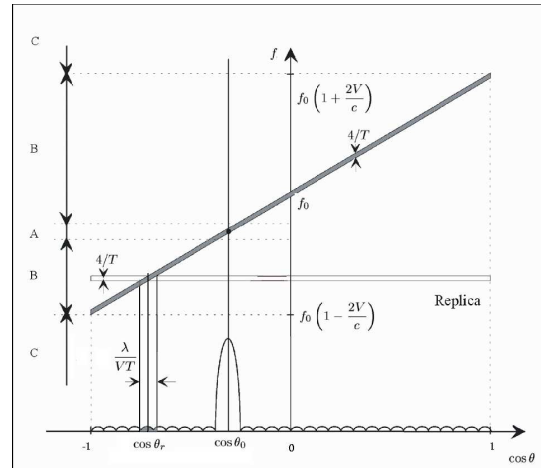


Fig. 5 : Reverberation power-CW

For Continuous Waveform pulses, consisting of a single frequency transmission of duration T, the width of its spectrum is small compared to the Doppler shift of targets. Detection performance strongly depends on the (absolute) radial speed of the target, on the beam pattern of the array and on the own ship speed [12]. For very slow targets (“Zone A” on Fig. 5), the reverberation through the main lobe of the beam-pattern is at the same frequency as the target, and since the range resolution is very poor, the performance is poor. For target with intermediate radial speed (“Zone B”) the reverberation at the target frequency arises from an angular sector in the side lobes of the beam-pattern, and the signal to reverberation ratio is improved by the side lobe rejection

(situation called “endoclobber” in radar). For very fast targets (“Zone C”), there is no reverberation in the target Doppler channel and the performance is very good (“exoclobber” situation in radar applications). Most situations of operational interest correspond to the “Zone B” case (which is the case represented on Fig. 5). We discuss in this section the application of adaptive beam forming to active sonar in CW Doppler mode. We restrict to the case of a linear receiving array aligned with its own speed. As mentioned earlier, in this mode the detection performances are related to side lobe rejection, and significant gains are expected from adaptive beamforming.

The main challenge is to obtain enough independent snapshots for the estimation of the covariance matrix. Reverberation in Doppler mode has a spatial structure which depends on the frequency, and also on time as the spatial structure of the environment is not stationary. For an array of length L , the interference associated to reverberation in each Doppler channel can be considered as arising from an angular sector of J “jammers”, whose central direction depends on the Doppler channel. The number of degrees of freedom required to cancel this interference is of an order 2 to 3 J . The number of independent snapshots available depends on the mode and array directivity. In CW mode, each slice time of duration T (pulse length) will provide one independent snapshot and the number of independent available snapshots per jammer and per pulse duration can be estimated.

As the number of available sensors on the array are several hundreds, the adaptive beamforming must be implemented in beamspace domain in order to reduce drastically the number of degrees of freedoms. It can be implemented either after conventional beamforming, by selecting the appropriate beams steered on the reverberation sectors as noise references (beam space beamforming), or at the output of conventional beams formed on selected subarrays from the full array (subarray beamforming).

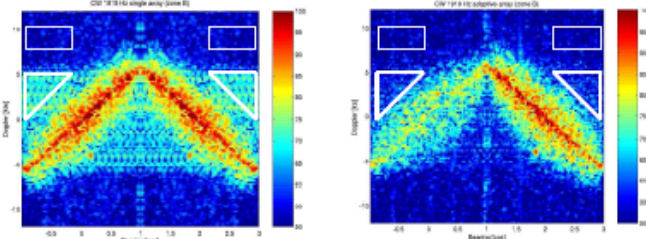


Fig. 6 : Reverberation power-CW: Doppler vs bearing reverberation levels at a given range

Triangle: Zone B estimation windows; Rectangle: Zone C estimation windows

Adaptive subarray beamforming was implemented at the output of replica correlation on a triplet array. The array consists of triplets of hydrophones fitted within a hose towed by the ship. The acoustic length of the array is close to 20m, for an external diameter of 80 to 90mm. Each triplet consists of equally spaced hydrophones fitted on a circle in the section of the hose. The triplets are equally spaced over the length of the array. The sensor arrangement can be seen as a set of three identical and parallel line arrays fitted within the hose. In each

Doppler channel, the three identical linear subarrays were selected from the main array. Conventional beams were formed on each subarray, and each identical triplet of primary beams were processed adaptively. The covariance matrix was estimated over several successive independent snapshots in time. The parameter VT/L was equal to 1.07. Measured gain averaged to 18dB on the signal to reverberation ratio (Fig. 6).

From a radar perspective, this processing can be described as an adaptive angular processing of the three channels -which is a simplified version of Space-Time Adaptive Processing (STAP), with adaptivity restricted to the spatial dimension, thus providing an efficient compromise between complexity and performance.

VI. CONCLUSION

This review of different applications of STAP processing across Thales Divisions clearly evidences the significant benefits brought by these techniques in the very different application areas considered here (which are only a subset of the concerned areas). It also demonstrates the requirement for continuous research efforts, aiming at mitigating the inhomogeneity limitations (eg no noise reference algorithms), reducing the complexity of the algorithms, or extending the algorithms to wide band signals.

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