

Multiband Passive Bistatic Radar Coherent Range and Doppler-Walk Compensation

Karl Erik Olsen

Norwegian defence research establishment

Email: Karl-Erik.Olsen@ffi.no

Jonas Myhre Christiansen

Norwegian defence research establishment

Email: Jonas-Myhre.Christiansen@ffi.no

Abstract—The work simulates the performance of a coherent Passive Bistatic Radar multiband processing algorithm. The aim of the work is to present improved range resolution by coherently combine non-adjacent DVB-T channels, while the improved Doppler resolution results from an increased coherent processing interval. The results are compared to the performance of single channel range and Doppler resolution.

I. INTRODUCTION

The aim of this work is to improve the single transmitter Passive Bistatic Radar (PBR) detection and tracking, namely improved target range and Doppler estimation. For FM radio, the bistatic range resolution is reported to be in the order of $3 - 30\text{km}$, while the corresponding number for the DVB-T is 40m , [1]. This work is focusing on how to improve the range resolution in the range correlation of the matched filter processing by exploiting multiple broadcasted channels from a single transmitter. The latter requirement is important in order to achieve the same geometry for all channels for the same target, i.e. same time-delayed processing. One of the goals of the work is to achieve the improved range resolution, while maintaining the high Doppler resolution from the relatively long integration time. It is believed that this work will fit nicely in a future system design alongside the improved detection performance of [2], [3], and the single transmitter target tracking of [4].

There are two special properties in the PBR systems relying on FM radio and DVB-T broadcast transmitters that should be exploited: 1) The broadcast transmitters are transmitting continuously, with a duty cycle of 100%, and the receiver of the FM and DVB-T based PBR systems are using antennas with stationary beams covering the surveillance area/volume 100% of the time. (Although not all systems are capable of processing continuously in real time due to the huge processing power needed). This means that the radar potentially is 100% time on target. 2) The FM radio and DVB-T based PBRs are using relatively long integration times (compared to the classical monostatic radars in similar roles), which yields very good Doppler resolution, and thus a potential for accurately separating targets, even though they are not separated in range.

The work will not include multiband processing techniques like interpolation and/or extrapolation. The actual information available in the different bands is pinpointed without interpolating and/or extrapolating, mainly due to the fact that the signal processing should be applicable within the processing

framework already in place in systems today, and the proposed algorithm is capable of that. But maybe most important is the fact that the bands are independent in terms of coding and content, as well as highly time varying bandwidth (FM radio). The works on interpolation and/or extrapolation are considering known waveforms behaving predictably across bands [5], which definitely is not the case for PBR systems relying on broadcasters of opportunity. However, it will not be impossible to obtain, but that would call for an extremely complex processing and is beyond the scope of this work.

This work use the combination of the multiband technique for PBR systems [6] and the coherent range and Doppler walk compensation [7]. The methods has been tested on simulated DVB-T data to see the effects of improved range and Doppler resolution on targets with range and Doppler walk.

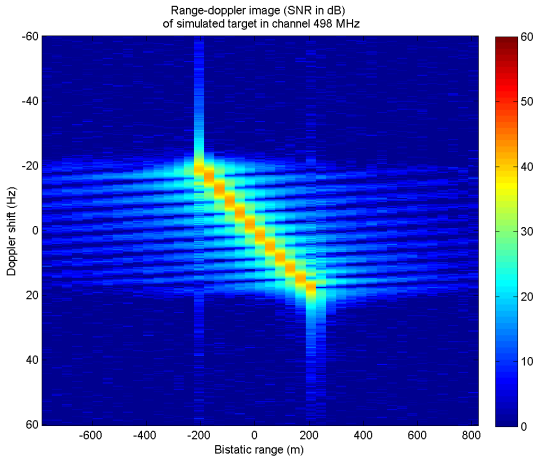
II. SIMULATIONS

A simple OFDM 64-QAM simulator is used to mimic the DVB-T signal. Pilot tones and TPS carriers are not applied, but all other DVB-T parameters for a set of norwegian terrestrial broadcast transmitters have been applied. The symbol data is drawn from a white gaussian process, and is according to [8] a good approximation to the DVB-T signal. Both bistatic velocity and acceleration has been applied to the simulated target, and three different bands have been simulated at carrier frequency 498 MHz, 690 MHz and 746 MHz and the CPI is 4 seconds. The target is at a bistatic range of 8km with a bistatic velocity of 95m/s and a bistatic acceleration of 3m/s^2 .

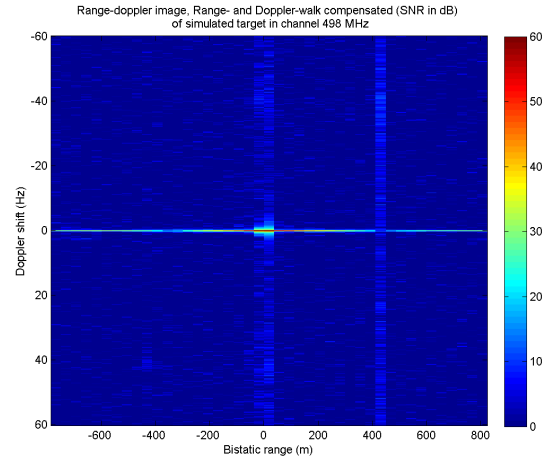
A. Range and Doppler walk compensation

For large bistatic velocities and accelerations compared to the CPI, range and Doppler walk will occur [9]. The method described in [7] coherently compensates for this and produces a focused target in range and Doppler, as well as applies the estimated velocity from the range Doppler matrix to compensate for range and Doppler walk coherently. During this algorithm the acceleration is estimated, and is used to compensate for the range and Doppler walk caused by the acceleration.

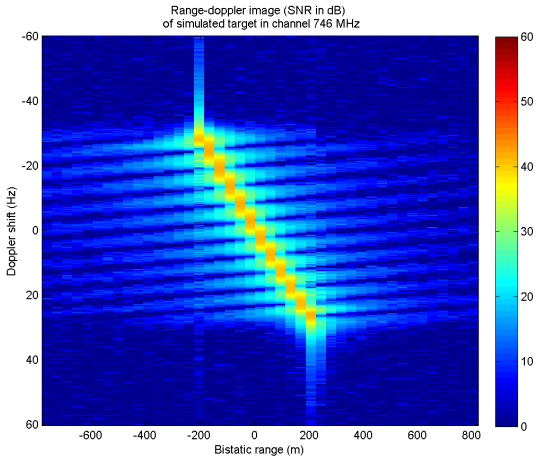
A simulated target generated in channels 498 MHz, 690 MHz and 746 MHz has been coherently compensated and is shown in figures 1b, 1f, 1d where the target is focused in the three channels. The non-compensated targets in figures 1a, 1e,



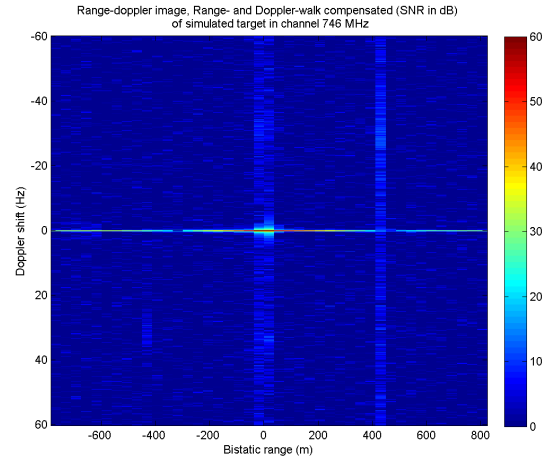
(a) Range Doppler image of channel 498 MHz showing range and Doppler walk



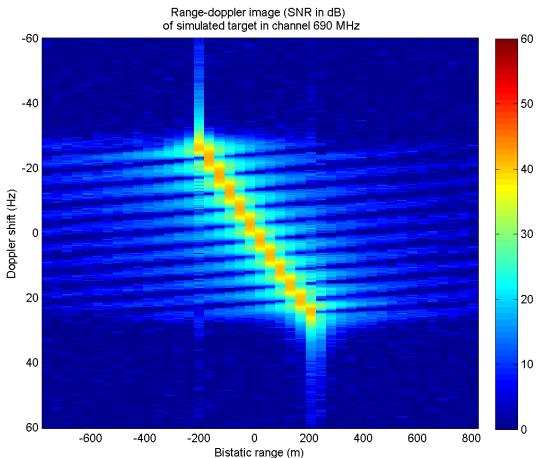
(b) Range Doppler image of channel 498 MHz after range and Doppler walk compensation



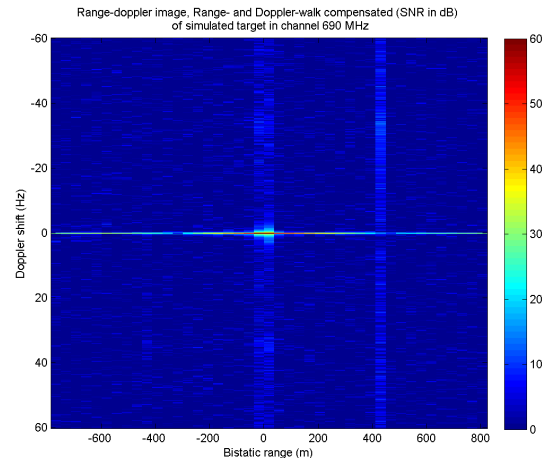
(c) Range Doppler image of channel 746 MHz showing range and Doppler walk



(d) Range Doppler image of channel 746 MHz after range and Doppler walk compensation



(e) Range Doppler image of channel 690 MHz showing range and Doppler walk



(f) Range Doppler image of channel 690 MHz after range and Doppler walk compensation

Fig. 1. Plots with CPI 4 seconds showing before (figures 1a, 1c, 1e) and after (figures 1b, 1d, 1f) range and Doppler walk compensation for channels 498 MHz, 746 MHz and 690 MHz, where the target is focused in both range and Doppler

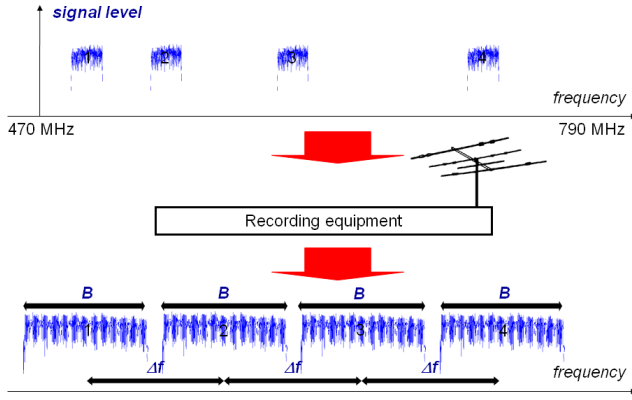


Fig. 2. This figure [6] show how the DVB-T channels are assembled into one band in order to increase the range resolution.

1c show how the range and Doppler walk stretch the target in both range and Doppler during the CPI.

The range and Doppler walk compensation is necessary in order to apply the multiband method because if no compensation is applied, the target would be stretched over several range and Doppler bins and an increased range resolution would give no new information of the target.

B. Multiband technique for PBR systems

The difference between the multiband method shown in [6] and multiple stepped frequency waveforms synthesized together in order to achieve higher range resolution [10] is that in the PBR case, no control of the transmitted waveforms can be assumed, nor their carrier frequencies.

In addition to this, the main high range resolution work is not considering coded waveforms for stepped frequency applications, and are transmitting non-modulated continuous waveforms processed in sequence. This work is considering independently broadcasted signals, consisting of an information carrying signal modulated to a carrier frequency. All channels are broadcasted simultaneously, and are processed simultaneously. This means an understanding of the importance of in-channel cross-correlation between the reference and surveillance channels as well as the out-of-channel cross-correlation between reference and surveillance channels, is needed.

Finally, by using different broadcasted channels in the correlation process, each of the channels will result in different Doppler shifts from the same target, as each of the channels are using different carrier frequencies. The strategy from [7] to compensate for the range and Doppler walk will ensure that the target stays within a range and Doppler cell throughout the CPI.

The multiband method is a method adapted to the waveforms used in a DVB-T based PBR system, and is used on simulated data. The range and Doppler walk compensated

target from figures 1b, 1d, 1f is used in the multiband method [6] in order to improve the range resolution on the simulated target. The new range resolution ΔR_N is for evenly spaced Δf 's given as

$$\Delta R_N = \frac{c}{N\Delta f}, \quad (1)$$

where N is the number of channels, Δf is the distance between channels and c is the speed of propagation. The parameters is shown in figure 2. The distance between ambiguities are illustrated

$$\Delta_{ambiguities} = \frac{c}{\Delta f} \quad (2)$$

Figure 3a shows a range cut of the target in each channel and multiband. The range ambiguities is placed with approximately 76m distance, and theoretically they should be at $\frac{c}{4 \times 10^6} = 75m$. The new range resolution is 25.6m, and theoretically $\frac{c}{3 \times 4 \times 10^6} = 25m$. The bistatic range resolution [11] in each channel is given by

$$\Delta R = \frac{c}{B} \quad (3)$$

Where B is the channel bandwidth, and in the DVB-T case approximately 8 MHz. This give a theoretical range resolution of 37.5m of a target in one channel. The target in figure 3a has a wider response in range than the single channel range resolution and is caused by target acceleration. The target acceleration is compensated for in each channel, but the compensation is not perfect for large accelerations.

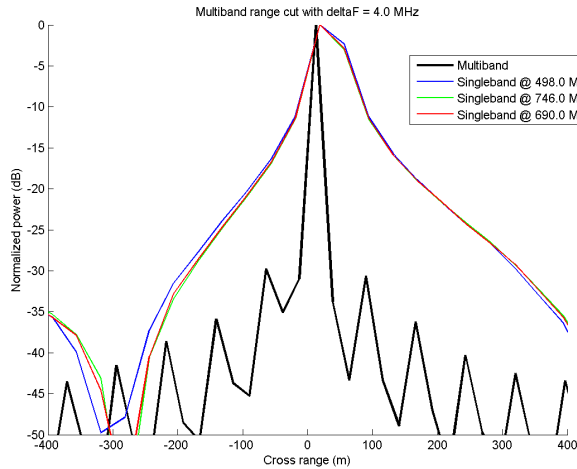
Figure 3b show the same target with a Δf set to 8 MHz. The multiband range resolution is theoretically $\frac{c}{3 \times 8 \times 10^6} = 12.5m$, and it is measured to be approximately 12.5m. The range ambiguities is twice as dense as for $\Delta f = 8MHz$, and this is expected from (3).

The range resolution is finer for larger Δf , but the range ambiguities is denser. The parameter Δf should be chosen such that the target can be identified and not mistaken for a range ambiguity. The Δf in this case should not be greater than 8 MHz, because if we chose a larger Δf there would be difficulties in selecting the correct peak as the target.

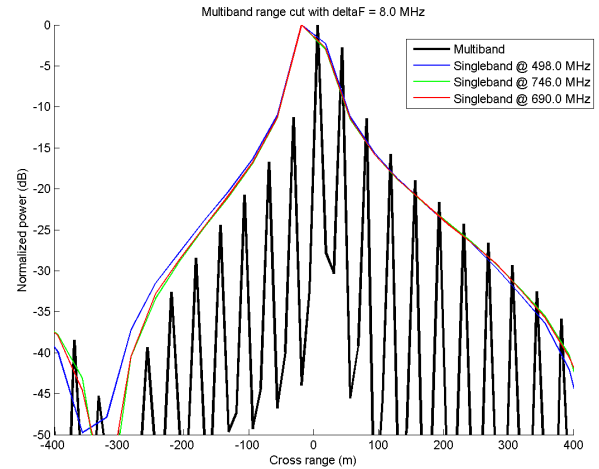
With a CPI of 4 seconds, 3 channels with a bandwidth of 8 MHz and a Δf of 8 MHz, leads to a Doppler resolution of 0.25 Hz and a range resolution of 12.5m. Figures 3c and 3d show that the Doppler resolution is maintained from single channel processing. This can lead to better information on the analyzed target, and it can be possible to see Doppler and range features of the target.

III. CONCLUSION

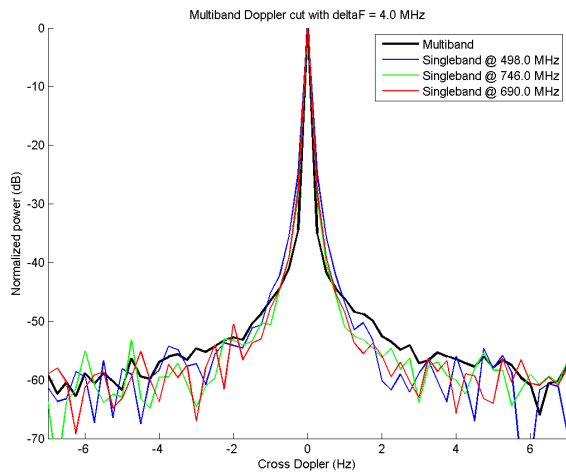
This work simulates an algorithm for increasing both the range and Doppler resolution. As longer CPI is applied in order to improve the Doppler resolution in DVB-T based PBR systems, the probability of range and Doppler walk increases. It has been demonstrated that the target is coherently compensated for both range and Doppler walk in each channel to focus the target.



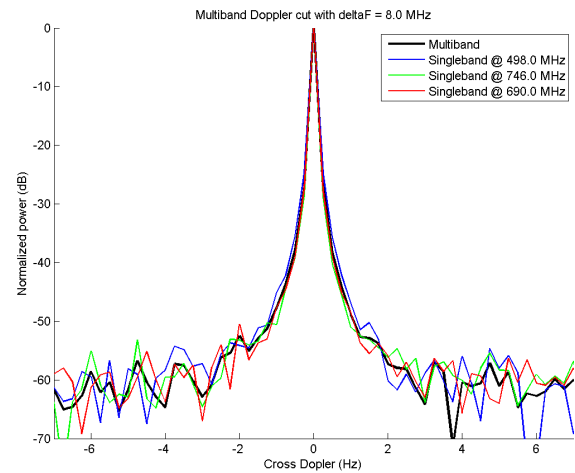
(a) Range cut of target using three channels with Δf as $4MHz$



(b) Range cut of target using three channels with Δf as $8MHz$



(c) Doppler cut of target using three channels with Δf as $4MHz$



(d) Doppler cut of target using three channels with Δf as $8MHz$

Fig. 3. Plots showing the range and Doppler compensated target with CPI 4 seconds and three broadcast channels at $498MHz$, $746MHz$ and $690MHz$. The range ambiguities is twice as dense for Δf equal 8 MHz than for 4 MHz, but the range resolution is better. The Doppler resolution is maintained from the single channel to multiband, since the CPI does not change by using the multiband method.

In our example, a multiband technique is used to combine several DVB-T channels in order to increase the range resolution. Simulations show that by using 3 channels of 8 MHz and a CPI of 4 seconds, a range resolution of $12.5m$ and Doppler resolution of 0.25 Hz is possible, thus additional information of a target could be extracted by using these techniques in a DVB-T based PBR system.

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