Time domain algorithms for detecting and mitigating mutual interference in FMCW vehicular RADARs

Abderrahim BELISSAOUI

***Abstract*—Interference in RADAR systems generally and especially in automotive RADAR is an arising issue which has emerged when automobile manufacturers started using RADAR sensors to enhance traffic safety, driver comfort and for autonomous driving applications. In this paper we present the effect of two state of the art algorithms on mutual interference detection and mitigation in FMCW RADAR systems. These tow algorithms were tested on an intermediate frequency (IF) signal real data in presence of mutual interference. IF signal data has been extracted from the 24 GHz SiRad Easy development Kit from silicon radar GmbH using octave scripts. Mutual interference modeling and simulation were performed using MATLAB software. Numerical results presented in this paper prove the detection and mitigation of IF signal interference component which means ghost targets components cancellation, whereas these algorithms need to be enhanced to detect and reject any kind of interference in FMCW Millimeter-Wave RADAR through maximizing signal to interference plus noise ratio (SINR).**

***Index Terms*—Vehicular RADAR, FMCW, Millimeter Waves , Interference Mitigation, SINR.**

I. INTRODUCTION

Nowadays, RADAR sensors are a key component in automotive active safety and driver comfort applications, the developers and constructors of these technologies use RADARs to enhance traffic safety by preventing any probable collision and also for driving comfort and autonomous applications. The commonly used RADAR technology in automotive applications is the Frequency Modulated Continuous Wave RADAR (FM-CW) and that is because of its simple architecture and high performance for short range applications, e.g Automatic Cruise control and lane change assistance. Automotive Radars operate at 24 GHz, 77 GHz bands and recently the 79 GHz band was allocated for automotive Radars. An FM-CW RADAR system emits and receives in continuous manner frequency modulated Electromagnetic waves, these reflections are then mixed with the transmitted signal to obtain an new signal called IF signal which the RADAR digital processor process and extracted targets measurements from, namely range, Doppler shift, and angle. In areas where vehicle are equipped with radar sensors , the received signal from environment is always a sum of the target echo and interference. An interference component in the IF signal reflects in as a ghost target in the Range/ Doppler map, and the classical detectors are usually unable to mitigate this false detection. Recently, some research projects e.g MOre Safety for All by Radar Interference Mitigation (MOSARIM) research project [...] in which the authors worked on analyzing the effect of mutual interference on automotive RADARs and usually results were just some recommendations and hardware solutions, also many patents [3.1.1, 3.1.15, 3.1.18]were published recently propose different techniques there are centered around detect and avoid, detect and repair or communicate and detect and avoid interference in vehicular RADAR systems. The effect of these techniques and methods on interference mitigation automotive RADAR varies from very low to medium due to the high similarity between IF target signal and IF interference component. On the other hand, numerous research papers addressed the mutual interference issue in automotive RADARs differently, an investigation on interference mechanisms in automotive radar sensors is detailed in [investigations of mutual]. In [stochastic...]authors propose a stochastic geometry approach to model interference and design a complex filter to suppress the interference component. A radar-to-radar interference suppression algorithm in distributed networks RADAR sensors is presented in[2], This algorithm first uses an iterative filtering algorithm to suppress the radar-to-radar interference and then separately matched filtering for each radar. Compressed sensing and sparse recovery algorithms-based interference mitigation techniques are used in [..], these techniques require less computational effort, however they require a specific radar architecture (compressed sensing RADAR). The present paper is structured as follow: Section 1 describes the basic FM-CW RADAR principle, in section 2, we demonstrate the effect of mutual interference on vehicular RADAR and in the section 3 we present weighted envelop techniques techniques and their effect on interference mitigation in automotive RADARs and then we explain and demonstrate the technique we propose to mitigate interference followed then by simulation results and comparisons.

II. AUTOMOTIVE RADAR AND FMCW TECHNOLOGY

A. *FM-CW automotive RADAR*

Automotive radar utilize the Linear Frequency Modulation Continue Waveform to transmit an RF energy through an an-

Identify applicable funding agency here. If none, delete this.

tenna into surrounding environment.The RX antenna collects reflected energy from different targets and conveys it through a pre-processing circuit(LNA). The mixing circuit output is the IF signal which contains the information on time delay and Doppler shifting frequency, these tow parameters give information on target range and relative velocity.

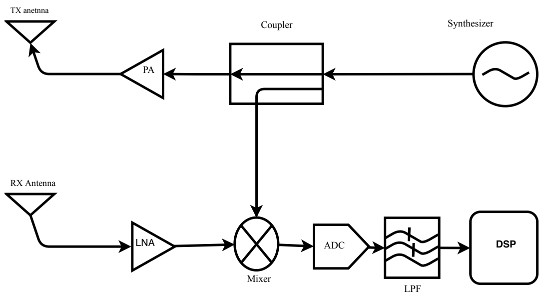

Fig. 1. Bi-static FM-CW RADAR architecture.

The FM-CW RADAR transmits a sequence of an up or down chirp or up-down chirp to ensure both target range and relative velocity estimation. Selecting the type of chirp and designing the transmitted signal for FM-CW RADAR system is a crucial step to get better separation capabilities between closely located targets (Range resolution).

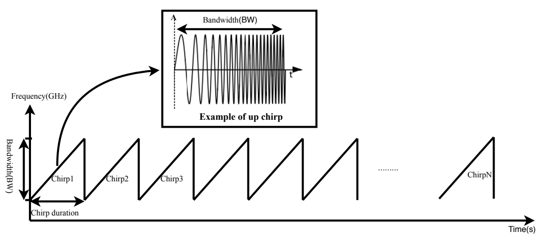

Fig. 2. Sequence of Up-chirps in Time-Frequency domain.

Considering f_c carrier frequency, Bw sweep bandwidth and T_c of the chirp, The equation of a single Up-Chirp can be written as follow:

$$c(t) = A_c.cos(\phi(t)), \tag{1}$$

Where, $\phi(t) = 2\pi t(\frac{Bw}{2T_c}.t + (f_c - \frac{Bw}{2}))$ is chirp phase function and A_c is chirp amplitude.

Then the FM-CW RADAR transmitted signal is the sum of the N chirps :

$$S_T(t) = \sum_{k=1}^{N} c_k(t), \tag{2}$$

B. Range/Doppler estimation

The received signal reflected on the RX antenna is a copy of the transmitted signal shifted in time and phase, in addition of an additive noise and unwanted reflections from the RADAR working area such as clutter, multipath and interference.In this section, we assume that the received signal is constituted only from surrounding environment obstacles echos.

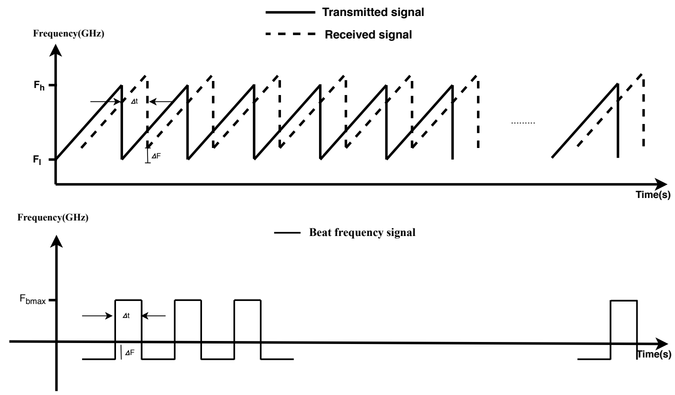

Fig. 3. FM-CW principle.

Mixer output or IF signal is the result of a simple The IF signal is the result of a simple multiplication of transmitted and received signal. The mixer stage in FMCW RADAR architecture is always followed by a low pass filtering to reject RF component and keep only the IF signal which contains beat frequencies.

We can now by using Doppler frequency and beat frequencies calculate Range and relative velocity of a single target.

Range equation:

$$R = \frac{cT_c f_b}{2Bw}, \tag{3}$$

Doppler equation:

$$Vr = \frac{\Delta f \lambda}{2}, \tag{4}$$

Detection process in vehicular RADAR systems is based on performing a 2D-FFT to compute simultaneously both range and relative velocity of multiple targets, then applying a Constant False Alarm Rate (CFAR) detector to remove noise and clutter. To locate targets in working environment, a multiple transmitting and receiving channels are required and a third FFT should be performed to detect the Direction of Arrival (DoA) of each target signal, thus the angle where a Target is located can be determined using the DoA information.

III. Interference effect on FMCW mmW RADARs detection performance

A. Vehicular RADARs interference scenarios

In radar-congested environments, vehicular RADAR detects objects that are not designed to be detected. In this subsection we present a simple interference scenario. three vehicle in this scenario are all equipped with RADARs operating in 76 GHZ to 81 GHz band.

In rear and forward facing in traffic scenario shown in Fig.4, The vehicle V1 radar sensor must detect the V2 as an

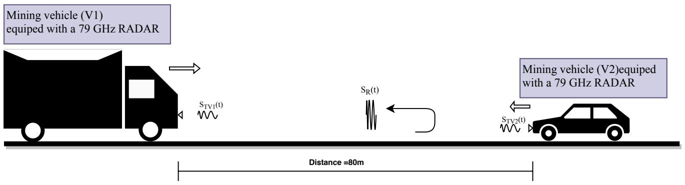

Fig. 4. Simple scenario of mutual interference.

obstacle to avoid collision and the same for the V2 RADAR, it has to detect the V1 echo signal and interpret it as an obstacle not as a ghost target. In fact, each vehicle-RADAR will receive other target echo signal and its transmitted signal, thus the received signal will be the sum of targets echos and interference component in addition to noise, clutter,etc. Considering for this scenario, V1 RADAR is bi-static and it transmits S_{V1Rx} continuously.

B. Mmw-RADAR Mutual Interference modeling

In a real scenario, for a I interfered RADARs and M Targets, received signal formula for a given RADAR at an instant t is :

$$S_R(t) = S_{In}(t) + S_{Ech}(t) + \gamma(t), \tag{5}$$

Where:

$$S_{Ech}(t) = \sum_{m=1}^{M} A_{R_{ech,m}} cos(2\pi(t - t_{d,m})(\frac{Bw}{2T_c}.(t - t_{d,m}) + (f - \frac{Bw}{2} + f_{d,m}))),$$

$S_{Ech}(t)$ is targets echo signal and

$$S_I(t) = \sum_{i=1}^{I} A_{In,i} cos(2\pi(t - t_{d,i})(\frac{Bw_{Int,i}}{2T_{cInt,i}}(t - t_{d,i}) + (f - \frac{Bw_{Int,i}}{2} + f_{d,i}))),$$

is the interference component and and $\gamma(t)$ is a thermal noise. $A_{In,i}$, $t_{d,i}$, $T_{cInt,i}$, $f_{d,i}$, respectively, the i-th interference amplitude, time delay, sweep time and Doppler frequency .

Thus, for the scenario shown in Fig.4 ($M = 1$ obstacle (target) , $I = 1$ interference), the received signal at an instant t by V2 RADAR RX antenna in absence of clutter can be written as follow:

$$S_{V1Rx}(t) = S_{InV2}(t) + S_{EchV2}(t) + \gamma(t) \tag{6}$$

And the V1 RADAR IF signal is:

$$S_{IFV1}(t) = S_{V1Rx}.S_{V1Tx} \tag{7}$$

Supposing that V2 RADAR is for long range (Long Range RADAR) applications and V1 RADAR is for detecting near obstacles in short ranges (USRR, SRR). Both V2 and V1 RADARs use an up-chirp sequence based transmitted signal. Consequently, the V1 radar received signal in time-frequency domain for this scenario can be presented as follow ...

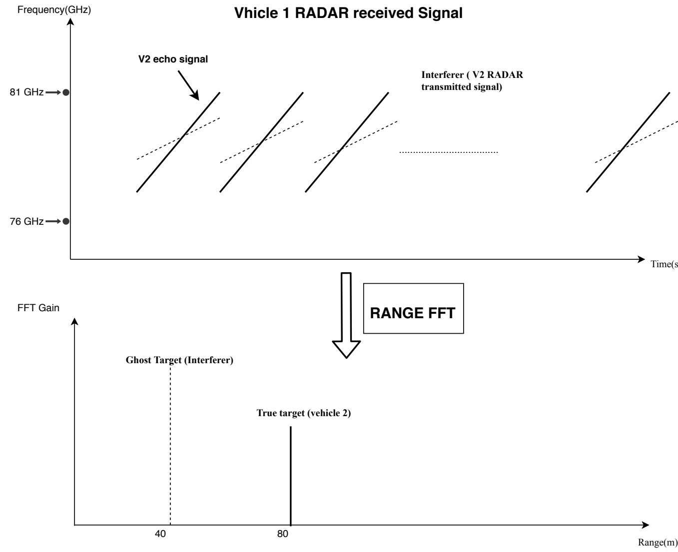

Fig. 5. Simple scenario of mutual interference.

As shown in the figure 5, interference component peak power exceeds true target signal peak power, hence a detector even it is adaptive such as CA-CFAR, OS-CFAR cannot reject ghost targets, thus detecting ghost target component in time or frequency domain and then filtering or canceling it seems to be an efficient solution.

IV. Locating and filtering interference in FMCW RADAR

A. Weighted-Envelope Normalization algorithm flowchart

WEN algorithm is an enhanced version of clipping out method. clipping out method is a simple algorithm consists of two steps; first step is to design a bound by setting up a maxima and minima of the IF signal and second step is to clip out IF signal components outside of the bound. the aim of this method is to locate interference in IF signal and mitigate them before signal processing .

The WEN algorithm consists of four steps (Fig.6).

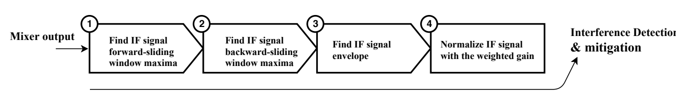

Fig. 6. WEN algorithm flowchart.

AWEN algorithm is an enhance version of WEN, it is based on the some routine, the only difference between WEN and AWEN is in the way of how they compute the ...

B. SiRad Easy RADAR interference effects minimization using Weighted-Envelop Normalization (WEN) and Advanced WEN

1) Simulation results:

- Case 1: RADAR IF signal without interference.
- Case 2:RADAR IF signal with interference.

C. Interference localization and mitigation method based ambiguity function and adaptive threshold function

V. Conclusion and perspectives

We discussed in this paper the interference effect on Millimeter Wave RADAR detection and a pre-processing method based ambiguity and adaptive threshold function has proposed and implemented. Measurement results

References