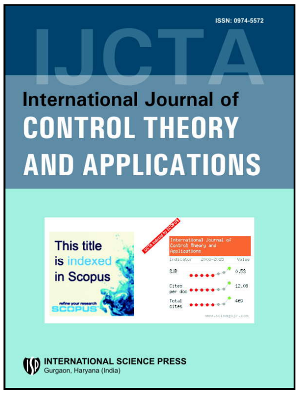

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Development of Intelligent FMCW radar for vehicular target detection

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Abstract: With the current technological advancements many vehicle manufacturers are embedding frequency modulated continuous wave radars (FMCW) [1] as active safety systems to reduce fatalities by protecting the driver and passengers from accidents. 77GHz FMCW radar sensors are chosen in the automotive applications as they are unaffected by harsh environmental conditions such as low light quality and poor weather. In this paper, an array antenna (AA) is used with Space time adaptive processing (STAP) for performance improvement of 77GHz automotive FMCW radar to detect moving objects and Doppler processing for the same is proposed. The AA generally mitigates hardware complexity, weight and cost. STAP radar processing combines temporal and spatial filtering that can be used to null the jammers and detect slow moving targets. We also proposed intelligent FMCW radar embedded in the next generation e vehicle this can intelligently utilize its front end radar transceiver for radar sensing (vehicles/ pedestrian) and the rear end communication transceiver for communicating with road side unit when the car is approaching a junction and leaving the roadside unit behind. To reduce the co-channel interference power control method might be used. Similarly when the car is approaching a road side unit front end communication transceiver would be used for communicating with road side unit and the rear end radar transceiver would be used for radar sensing.

Keywords: Array Antenna, STAP, Radar, FMCW, VANET.

1. INTRODUCTION

As 77GHz FMCW radar sensors can combat harsh environmental conditions for automotive safety applications these radars have become the first choice for vehicle manufacturer [2],[3]. FMCW radars are smaller to embed, cheaper to manufacture and power requirement is lesser [4]. Because of the very narrow pointed beam width 77 GHz long range radars are widely accepted for automotive safety in Vehicular ad hoc network (VANET). Moving target or vehicle detection is one of the primary issues in safety applications for VANET, there a common Doppler radar is used for Moving target detection and velocity measurement [6]. Doppler may be produced using Radars such as Coherent pulsed (CP), Continuous wave (CW), or Frequency modulated (FM)- CW [7]. Target velocity is determined by the Doppler radar wherein frequency modulated continuous wave (FM-CW) radar measures speed (velocity) and distance (range). In FMCW radar target range and velocity is estimated from the received beat frequency signal [8]. As the received signal is a time-delayed replica of the transmitted signal the time delay Ät is related to the range. At any moment during the signal sweep the frequency difference, f_b, is called the beat frequency. The time delay is derived from this beat frequency and then is translated to the range. Here we have assumed that the initial frequency, centre frequency, modulation bandwidth, time delay and period of chirp signal are f_0 , f_c , B, t_d, T respectively. For a moving target received signal will be having a Doppler shift in addition to the frequency shift for time delay td. These two beat frequencies one for up chirp (f_{bu}) and another for down chirp (f_{bd}) are used to calculate the range and relative velocities for moving target by equation no 1 and 2 respectively.

$$R = \frac{CT \frac{|fbu + fdu|}{2}}{2B} \tag{1}$$

$$V = \frac{C \frac{|fbu - fdu|}{2}}{2fc} \tag{2}$$

With the advancement of digital signal processing much signal processing are embedded in the back end of the FMCW Radar to enhance the performance for obtaining better imaging in case of multi-target detection[9] in dynamic mobile environment. The latest popular technology is STAP incorporated with array antenna [10]. STAP is a signal processing technique most commonly used in radar systems considering both the space and time. Here adaptive array processing algorithms aids in target detection. Radar signal processing benefits from STAP in areas where interference like heavy ground clutter is a challenge [11]. Through careful application of STAP enhanced sensitivity in target detection may be achieved.

In other cases such as a moving target has such a slow motion that Doppler processing is unable to detect against stationary background clutter – such as a person or vehicle moving at walking speed. A technique called space time adaptive processing (STAP) can be used to find targets that could otherwise not be detected.

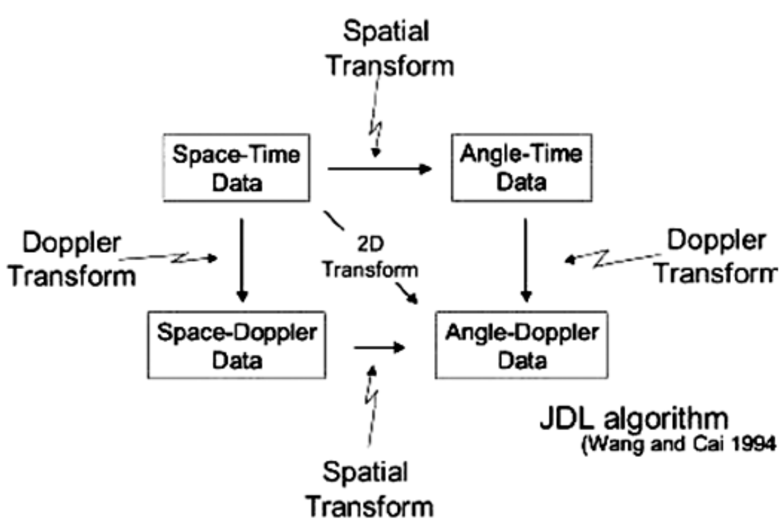


Figure 1: STAP Processing Domains

STAP processing requires use of an array antenna. However, in contrast to the active electronically scanned array (AESA), STAP algorithms involve the use of multiple antennas on the receiving platform. The space diversity is provided by spacing the antennas apart by at least half wavelength, this helps combating the fading effects. Using different algorithms the incoming signals on each antenna element are adaptively weighted in order to steer the antenna gain towards the desired signals while placing nulls in the direction of unwanted noise and interference. Also in case of the AESA steering is done only in one dimension but in STAP the array can be steered in two dimension in both elevation (up and down) and azimuth (side to side).

We have organized the rest of the paper as, first we defined the existing problem for automotive radar vehicle detection, then the solution the problem is proposed, followed by some simulation results and analysis with a comparison table showing the performance improvement by STAP processing and conclusion at last.

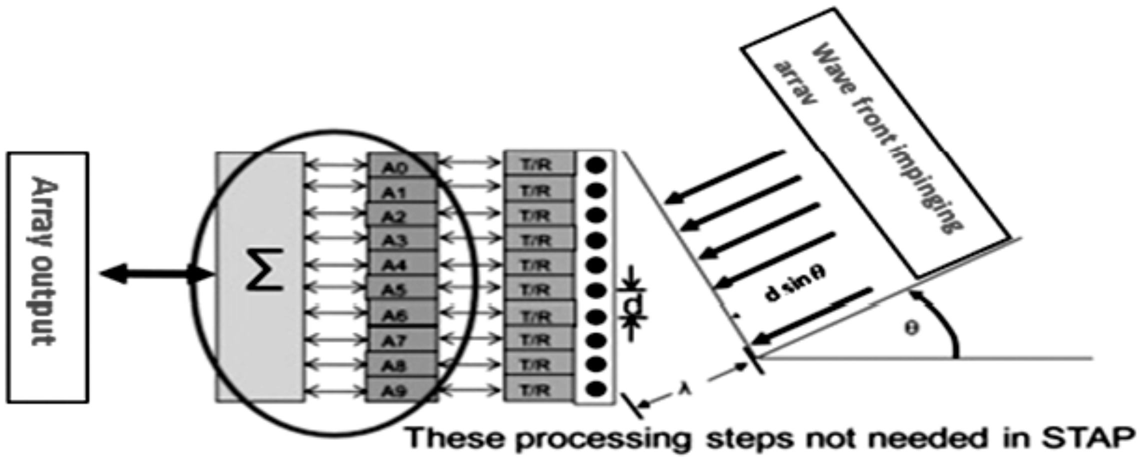


Figure 2: Array antenna necessary for STAP radar

2. PROBLEM FORMULATION

Detection for small targets has become a critical application for High Resolution (HR) radar [12], specially the buoys, human divers, or small boats in the marine surveillance radar. Since HR reduces the resolution cell size in the scenario illuminated by a radar system, the statistical assumption that the sea clutter is Gaussian or Rayleigh distributed may not be appropriate for the real world.

Problem 1: In same way Heavy ground clutter may null the object detection in the real highway lanes [13]. This may deteriorate the performance of the automotive radar[14][15] such as estimating the relative velocity resulting in maximum unambiguous velocity estimation, hence the target car will appear slower in Doppler processing and the range-Doppler coupling would be erroneous[16][17] and cannot be correctly compensated. Resulting in misinterpretation of range and the relative velocity of target car. Traditionally, the backscattered energy of large obstacles with high Radar Cross-Section (RCS), is generally greater than that normal clutter in road, in this condition low RCS target detection is a major problem.

Problem 2: Considering a scenario where the internet of vehicles in the modern high speed lanes or urban lanes are constantly communicating with the Road side unit(RSU) and simultaneously sensing objects such as pedestrian, nearby car etc to reduce fatalities or injuries. Communicating and sensing on the same carrier spectrum for simultaneous operation would be a big problem due to inter carrier interference (ICI) and receiver saturation.

3. PROPOSED SOLUTION

To mitigate the problem of ground clutter and correcting the range Doppler coupling space time adaptive processing (STAP) is proposed. For FMCW Automotive Radar with array antenna for STAP Processing the unambiguous speed is more, which means that the maximum unambiguously detected relative speed estimate between two vehicles becomes close to the real value. As a result that the target car will not appear slower in Doppler processing and the range-Doppler coupling error can be correctly compensated.

For the 2nd problem of simultaneous communication and radar sensing with the same carrier spectrum without severe interference we are proposing here Intelligent FMCW radar. This takes care of the geo-location of the car. If the car is approaching a traffic junction leaving the RSU behind the front end radar transceiver will be operational for object detection and the rear end communication transceiver will start communicating with the RSU. Similarly if the car is approaching an RSU the front end communication transceiver will be operational for communicating with the RSU and the rear end radar unit will start sensing objects.

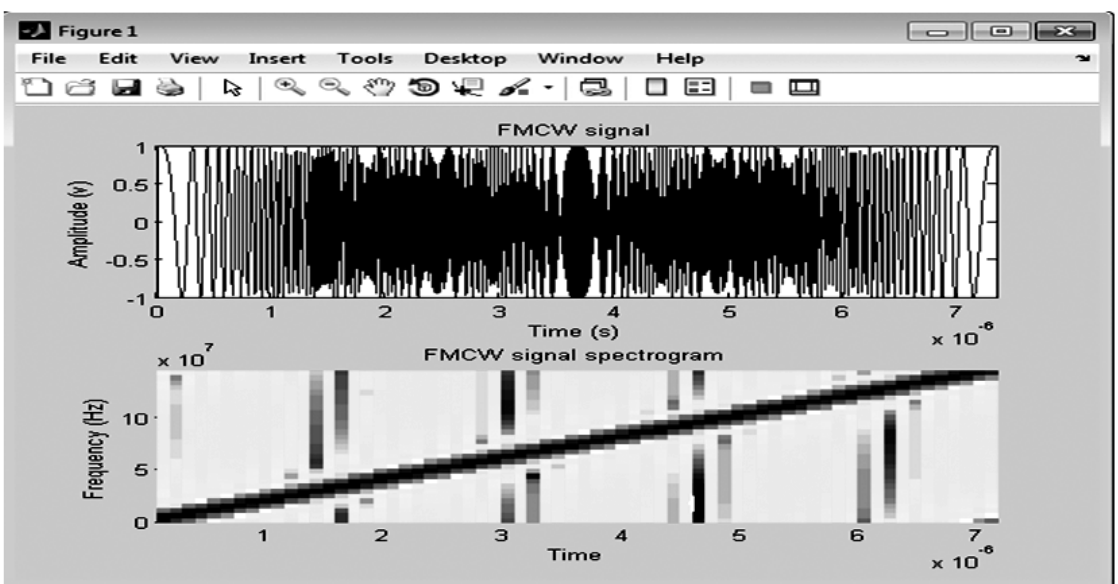
4. SIMULATION RESULTS

The system parameters for the FMCW radar is tabulated below,

Table 1
System parameters used for simulation.

System Parameter	*Units*	*Value*
Operating Frequency	GHz	77
Sampling Rate	MHz	150
Sweep Time	Micro Seconds	7.33
Sweep B.W	MHz	150
Maximum Target Range	Meter	200
Range Resolution	Meter	1
Maximum Target Velocity	Km/Hour	230
Maximum Beat Frequency	MHz	27.30

In high speed lane the target car is moving 50 m ahead of the car with the radar, at a speed of 96 km/h along the x-axis.



FMCW Automotive Radar with STAP

Figure 3: Transmitted FMCW waveform

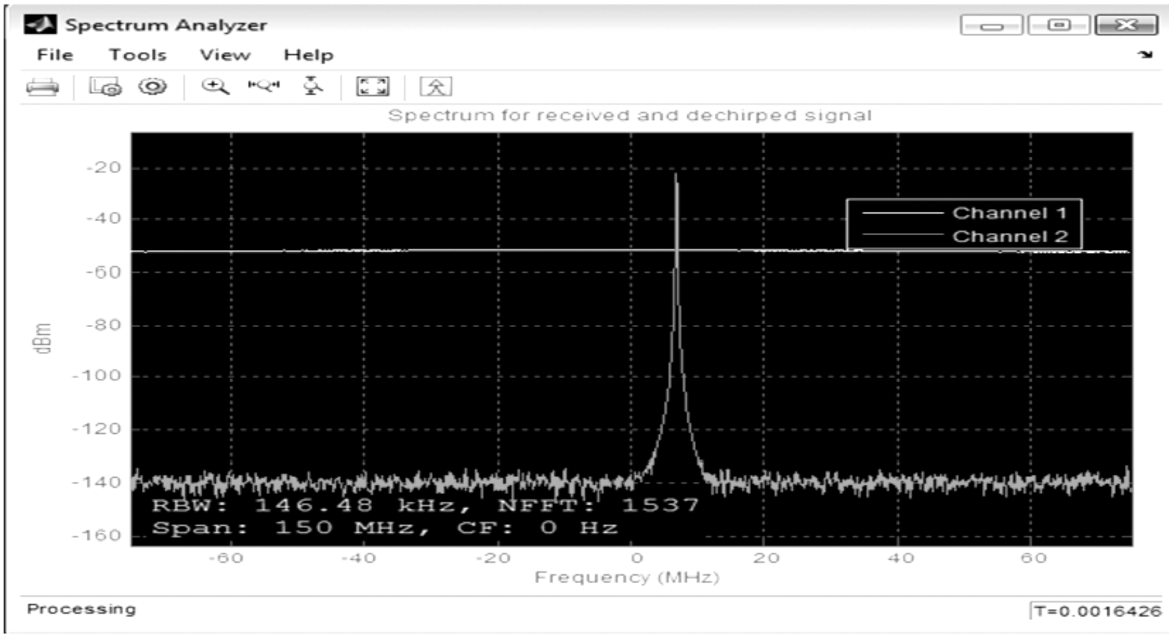


**Figure 4: Received Spectrum: Yellow- Wideband received signal,
Pink: Narrow Band Dechirped signal after sweeping through the entire band width.**

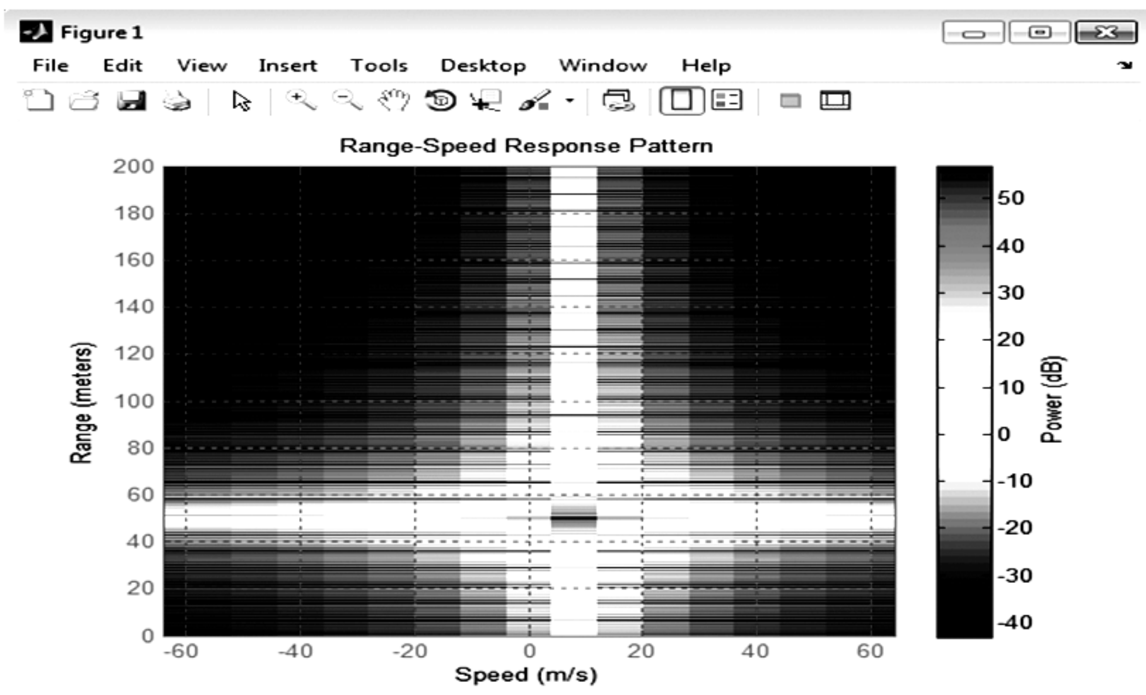


Figure 5: Range Doppler estimation from received sweeps.

The time delay is measured from the beat frequency and the delay is translated to the range. Automatic cruise control radar the maximum range the radar needs to monitor is around 200 meter and the system can distinguish two targets separated by 1 meter.

Table 2
FMCW RADAR with STAP processing output range and velocity

	Estimated Range in meter	*Estimated Relative Velocity in m/sec*	*Unambiguous velocity in m/sec*
FMCW automotive Radar with Phase Array antenna & STAP	49.9633	8.5492	3.7474

5. CONCLUSION AND FUTURE WORKS

For FMCW Automotive Radar with Single antenna the unambiguous speed is only 0.48 m/s, which means that the relative speed, 1.11 m/s, cannot be unambiguously detected. This means that not only the target car will appear slower in Doppler processing, the range-Doppler coupling also cannot be correctly compensated but for FMCW Automotive Radar with array antenna for STAP Processing the unambiguous speed is 3.7474 m/s, which means that the maximum unambiguously detected relative speed can be 8.4 m/s. This means that the target car will not appear slower in Doppler processing and the range-Doppler coupling is correctly compensated.

As future works we shall be concentrating on vehicular technology where the FMCW Radar would have the decision making ability of whether the front end or rear end transceiver would be used for sensing and communication, taking the past range measurements as reference and enabled with effective power control.

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