Doppler Correction for TDM-MIMO Radar and One Method for Velocity Ambiguity Resolution

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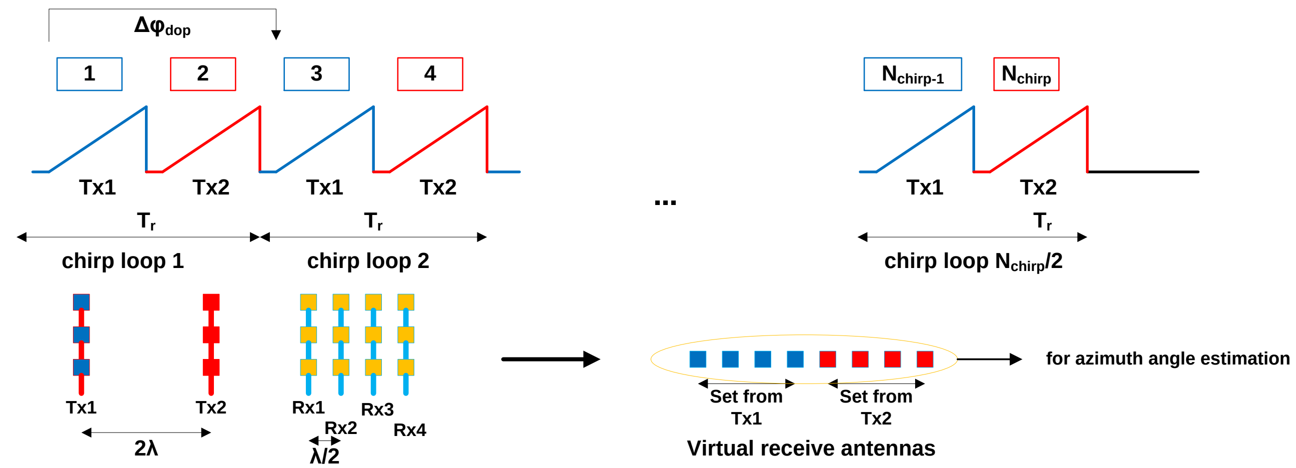
Introduction

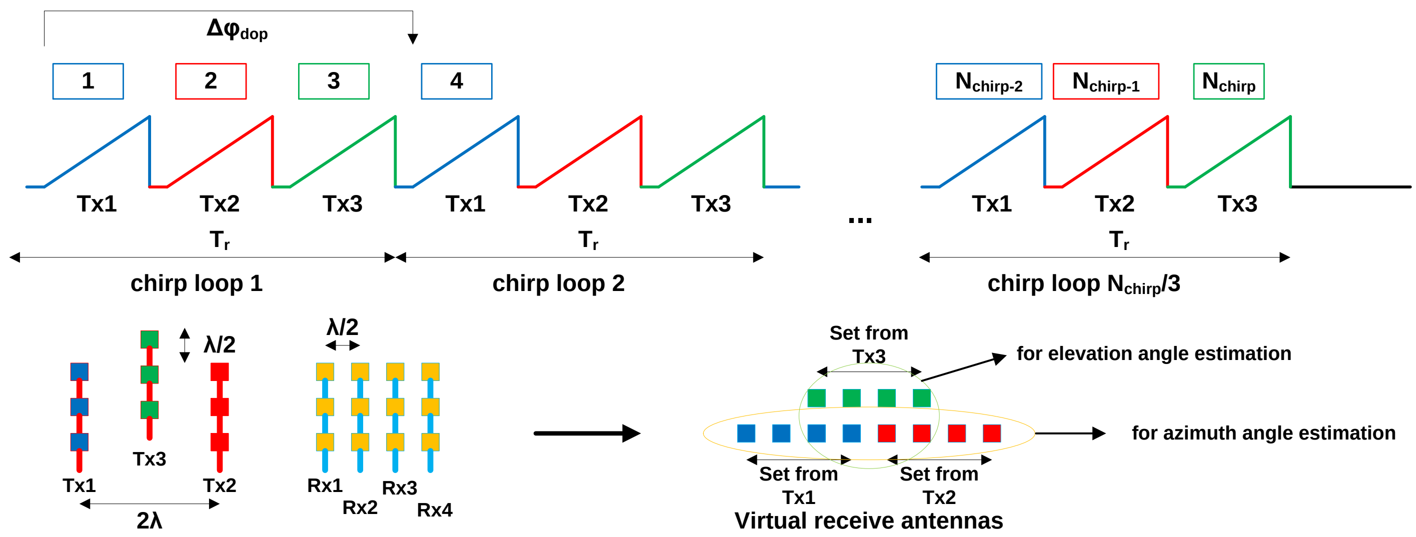
- TDM-MIMO is used in FMCW radar systems in order to improve the angular resolution. However, in the presence of Doppler frequency there is an additional phase shift between the virtual receive antenna groups corresponding to different transmit antennas. This causes an error in the target angle estimation – the phase change due to Doppler shift needs to be corrected.
- FMCW radar has a maximum unambiguous radial velocity, v_{max}, beyond which Doppler measurements are aliased. The situation is more pronounced in the case of TDM-MIMO, as the v_{max} is N_{tx} times smaller comparing to the case when only one transmit antenna is used (N_{tx} is the number of transmit antennas participating in TDM-MIMO).
- After the phase correction, the velocity can be disambiguated either :
  - At the detection layer -- we present here one simple method applicable to the TDM-MIMO with capacity to disambiguate detected velocity up to +/-3v_{max}. for the case of 3 transmit antennas.
  - At higher layers -- e.g. tracking module can correct (unroll) radial velocities and achieve correct object tracking irrespective of the target velocity. This method to disambiguate detected velocity is included in the tracking module implemented by TI.

TDM-MIMO with xWR1443

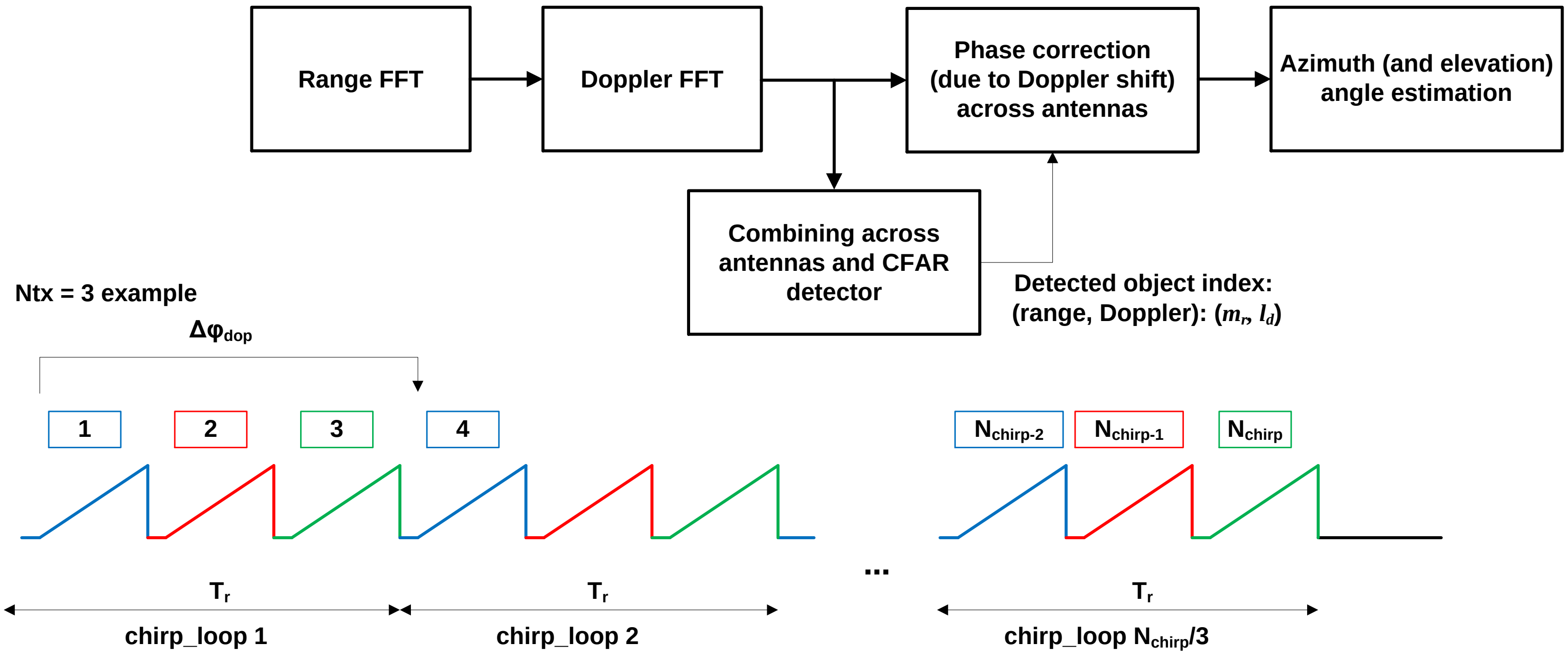
Case Ntx = 2: 8 virtual receive antennas



Case Ntx = 3: 12 virtual receive antennas



Phase Correction due to Doppler Shift Prior to Angle Estimation



The phase change between two chirps coming from the same transmit antenna due to the presence of Doppler shift is denoted by $\Delta\varphi_{dop}$. $\Delta\varphi_{dop}$ can be derived from the expression representing the phase of the sampled signal at the output of ADC (Appendix A) : $\Delta\varphi_{dop} = 2\pi\, l_d / N$,

where l_d is the Doppler index of the detected target in the 2-D FFT output and N is the Doppler FFT size. l_d is in the range $[-N/2, N/2-1]$. The phase correction is applied as follows:

- Set of receive virtual antennas corresponding to Tx1 (blue in the example): $\Delta\varphi_1 = 0$
- Set of receive virtual antennas corresponding to Tx2 (red in the example): $\Delta\varphi_2 = \Delta\varphi_{dop}/3$
- Set of receive virtual antennas corresponding to Tx3 (green in the example): $\Delta\varphi_3 = 2\,\Delta\varphi_{dop}/3$

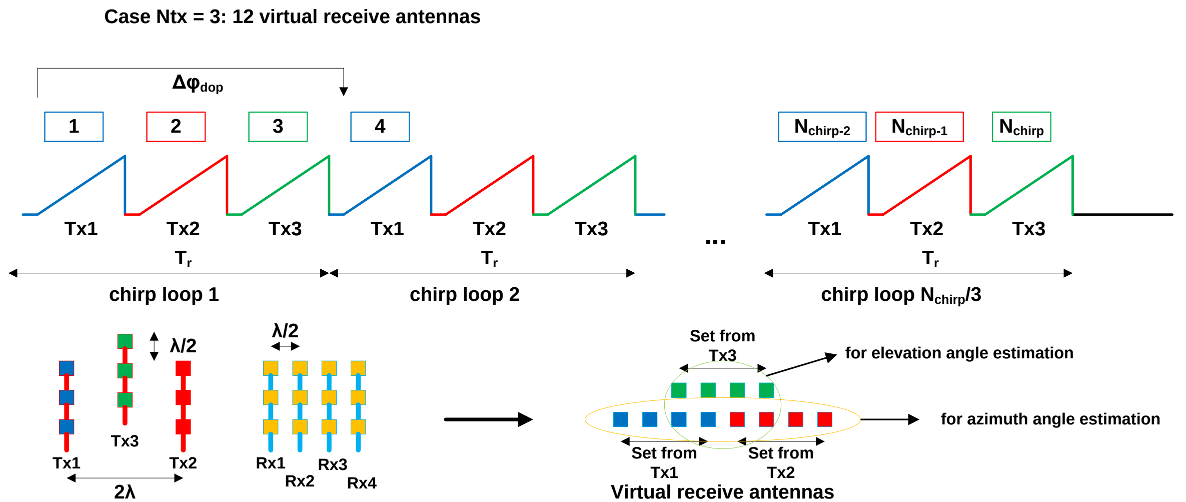
Phase Correction (Potential Aliasing Case): 3 Tx Antenna Case

When there is a possibility of phase change aliasing, three hypotheses are tested (Note):

H1: applied Doppler correction on the set of virtual rx antennas corresponding to the transmission on Tx2 is: $\Delta\varphi_{tx2,H1} = \Delta\varphi_{dop}/3$

H2: applied Doppler correction on the set of virtual rx antennas corresponding to the transmission on Tx2 is: $\Delta\varphi_{tx2,H2} = (\Delta\varphi_{dop}+2\pi)/3 = \Delta\varphi_{dop}/3 + 2\pi/3$

H3: applied Doppler correction on the set of virtual rx antennas corresponding to the transmission on Tx2 is: $\Delta\varphi_{tx2,H3} = (\Delta\varphi_{dop}-2\pi)/3 = \Delta\varphi_{dop}/3 - 2\pi/3$



Azimuth angular spectrum is compared for H1, H2 and H3:

If detected peak for H1 case is the largest, then $\Delta\varphi_{tx2,H1}$ is selected

If detected peak for H2 case is the largest, then $\Delta\varphi_{tx2,H2}$ is selected

If detected peak for H3 case is the largest, then $\Delta\varphi_{tx2,H3}$ is selected

Note: Hypotheses for phase ambiguities beyond +/-2π (+/-4π, +/-6π, +/-8π, …) fall into H1, H2 or H3

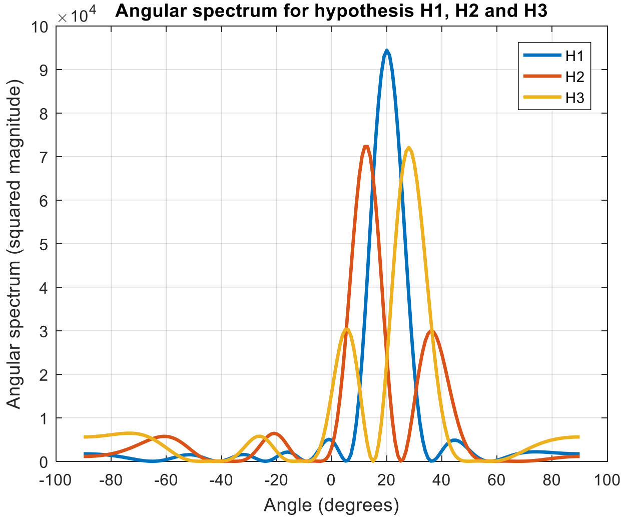
Phase Correction : 3 Tx Antenna Case, Elevation

Phase correction on virtual receive antennas corresponding to the transmission on the "elevation" transmit antenna, Tx3, is done in a similar fashion as on virtual receive antennas corresponding to transmission on Tx2 (azimuth, shown in the previous slide):

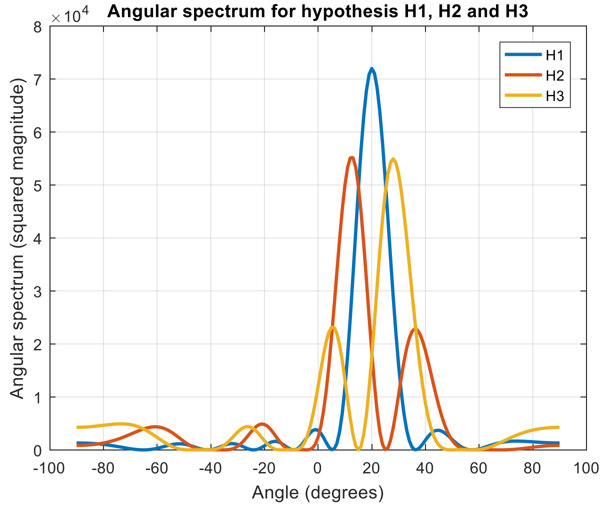
If hypothesis H1 is selected, then $\Delta\varphi_{tx3,H1} = 2\Delta\varphi_{dop}/3$
If hypothesis H2 is selected, then $\Delta\varphi_{tx3,H2} = 2(\Delta\varphi_{dop}+2\pi)/3 = 2\Delta\varphi_{dop}/3 + 4\pi/3$
If hypothesis H3 is selected, then $\Delta\varphi_{tx3,H3} = 2(\Delta\varphi_{dop} -2\pi)/3 = 2\Delta\varphi_{dop}/3 - 4\pi/3$

Phase Correction for 3 Tx Antenna Case (Examples, target at angle 20º)

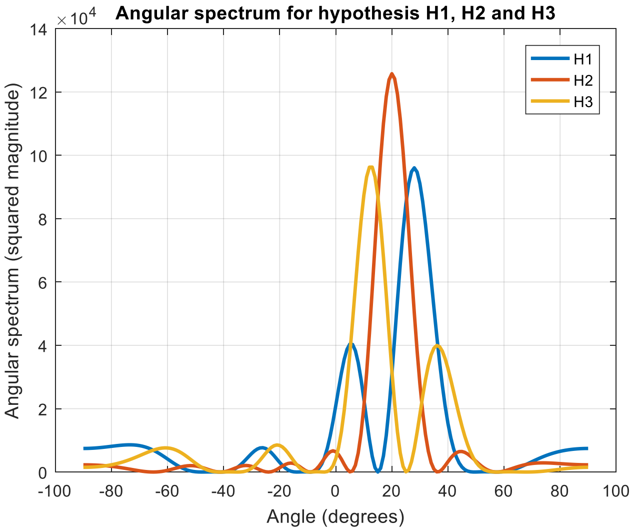
Example1: $v = v_{max}/4$, H1 selected



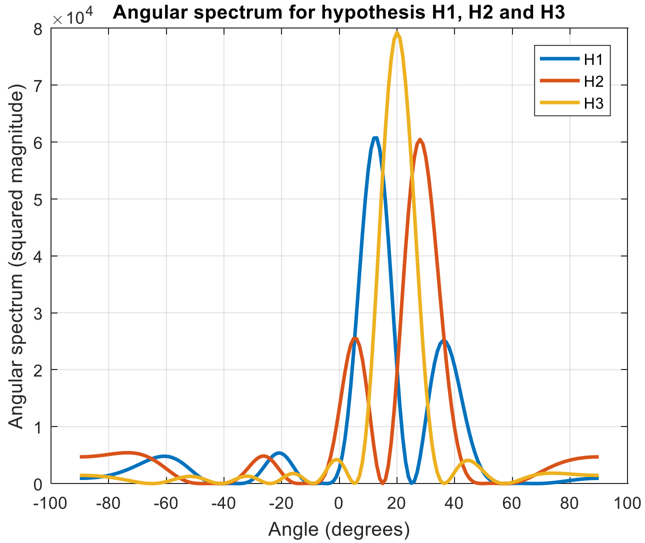
Example 2: $v = -v_{max}/4$, H1 selected



Example 3: $v = 5v_{max}/4$, H2 selected

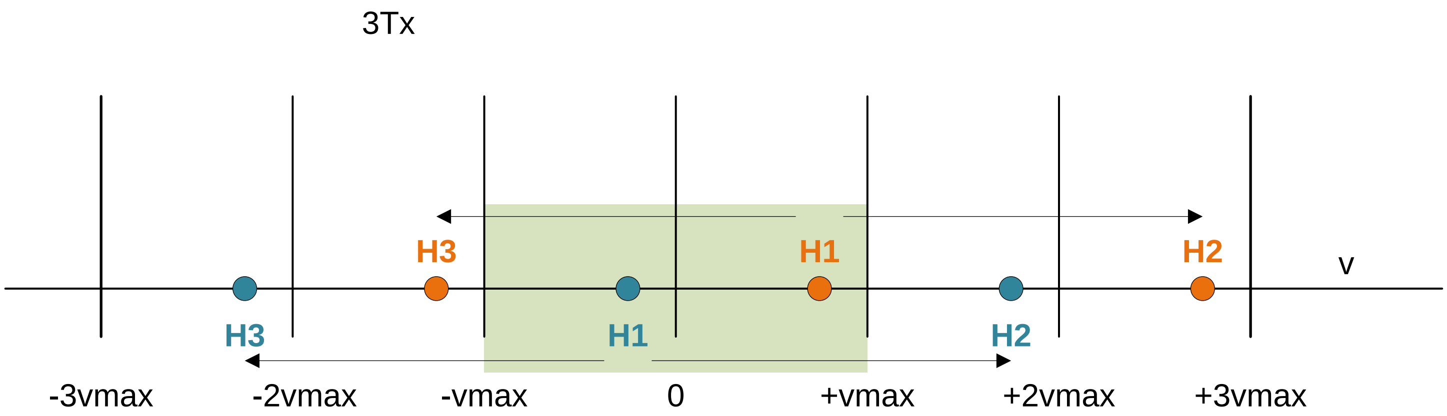


Example 4: $v = -5v_{max}/4$, H3 selected



Velocity Ambiguity Resolution – One Detection Level Method (*)

3 Tx antennas (N_{TX}=3) case:

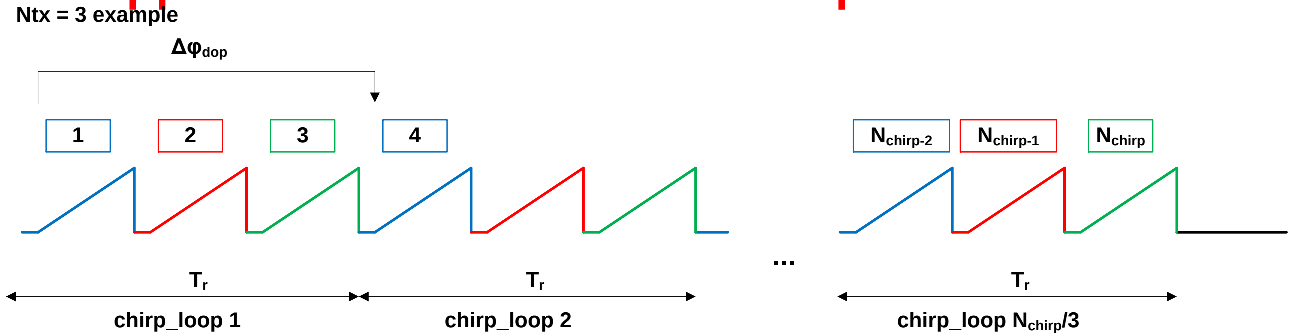


The three hypotheses defined previously are used here as well. The above figure describes how to unroll the velocity, depending on which hypothesis has been selected. The estimated velocity, v_{est}, is in the range between $-v_{max}$ and $+v_{max}$ (shaded area in the figure). The actual velocity, v_{actual}, will depend on the selected hypothesis:

If H1 is selected, then: $v_{actual} = v_{est}$
If H2 is selected, then: $v_{actual} = v_{est} + 2v_{max}$
If H3 is selected, then: $v_{actual} = v_{est} - 2v_{max}$

(*) The method described here uses simple processing at the detection layer level and can correct (unroll) velocities in the range $(-3v_{max}, 3v_{max})$ for the case of 3 transmit antennas, where v_{max} is determined by the chirp and chirp frame design. Other methods, which apply the processing at higher layers (e.g. tracking module) can correct (unroll) velocities in the range beyond $(-3v_{max}, 3v_{max})$ in this case.

Appendix A: Doppler Induced Phase Shift Computation in TDM-MIMO Radar



When orthogonality between the signals coming from multiple transmit antennas is achieved by transmission in non-overlapping time intervals we have the TDM MIMO radar, [1]. With respect to the above figure, the phase difference between the two chirps originating from the same transmit antenna can be approximated as:

$$\Delta\varphi_{dop} \approx 2\pi \frac{2v}{c} f_c T_r$$

where v is the object velocity, f_c carrier frequency, T_r chirp loop period (chirp loop consists of the chirps coming from all transmit antennas) and c is the speed of light. From [2] we also have that the velocity of the detected object is given by:

$$v = \frac{l_d c}{2 f_c T_r N}$$

where l_d is the detected target Doppler index, as shown in slide 4, and N is the Doppler FFT size. Combining the expressions for $\Delta\varphi_{dop}$ and v we get:

$$\Delta\varphi_{dop} = 2\pi \frac{l_d}{N}$$

The phase corrections applied to the virtual receive antennas related to the transmit antennas Tx1, Tx2 and Tx3 are:

$\varphi_1 = 0, \varphi_2 = \Delta\varphi_{dop}/3, \varphi_3 = 2\Delta\varphi_{dop}/3$, respectively.

[1] Texas Instruments, "FMCW Radar AoA Estimation Principles", internal report, March 2018
[2] Texas Instruments, "FMCW Radar Principles", internal report, February 2016