Fast-Time Clutter Suppression in mm-Wave Low-IF FMCW Radar for Fast-Moving Objects

Christopher Allen[1], Levi Goodman[1], Shannon D. Blunt[1], and David Wikner[2]

[1]Radar Systems & Remote Sensing Lab (RSL), University of Kansas
[2]Sensors and Electron Devices Directorate, US Army Research Laboratory, Adelphi, MD

THE UNIVERSITY OF KANSAS

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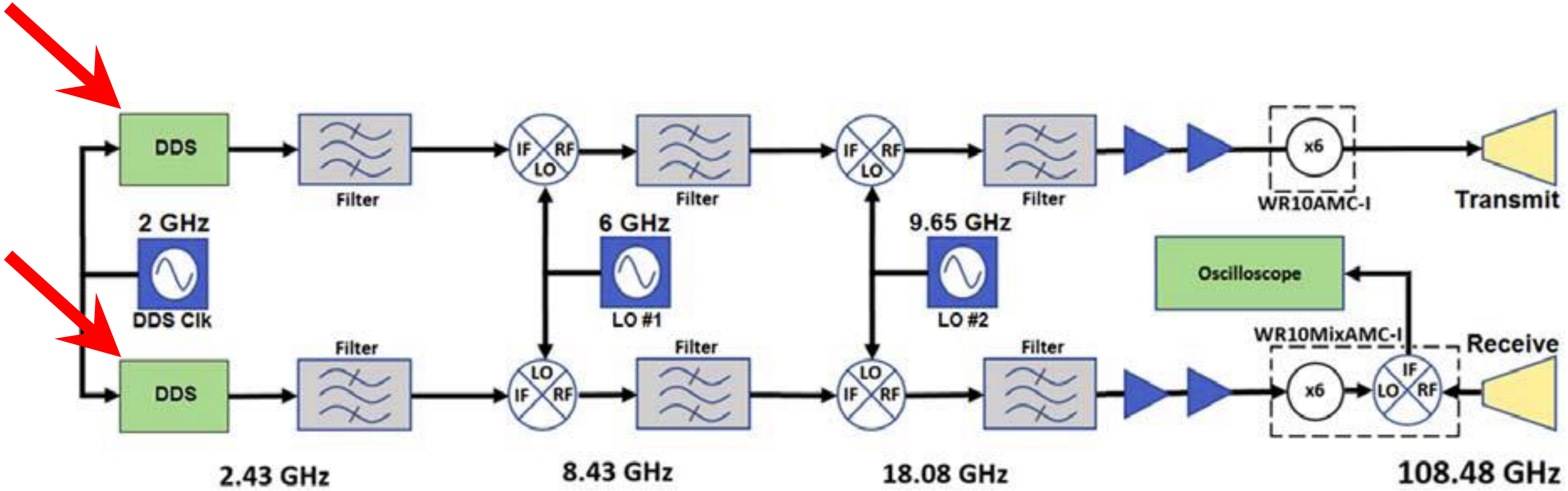
Motivation

- Explore FMCW radar's capability to simultaneously map static obstacles and fast-moving objects
  - fast mover's observable time is too short for convention range-Doppler mapping
- W-band implementation to support mobile applications
  - high Doppler sensitivity
- Heterodyne (low IF) mode to distinguish positive from negative frequencies
  - Symmetric triangular frequency-vs-time FMCW waveform used
- Clutter suppression separates fast-mover's echoes from static clutter
  - suppression performed in fast-time
- Experimentally demonstrated by firing "re-balls" (reusable paintballs)

KU

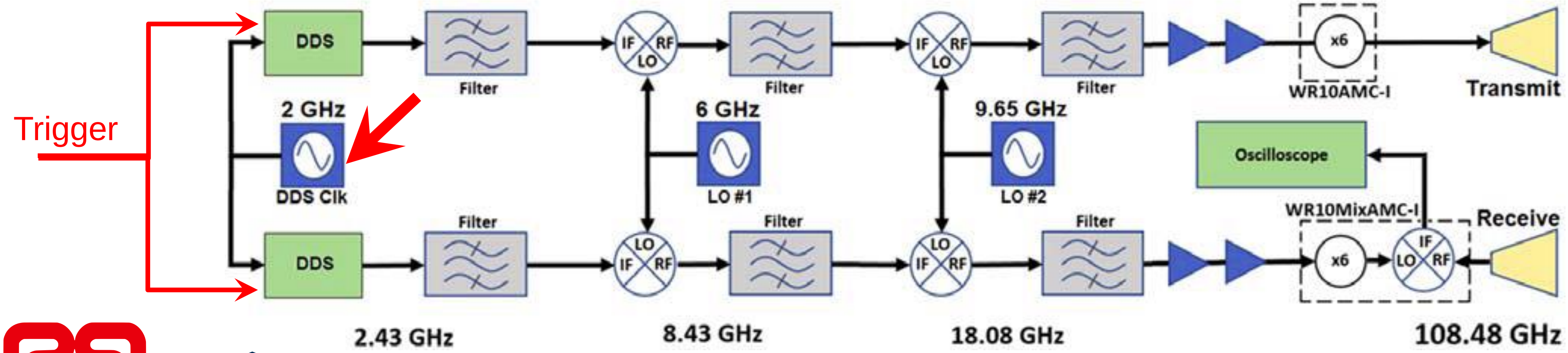
- Dual DDS waveform generation



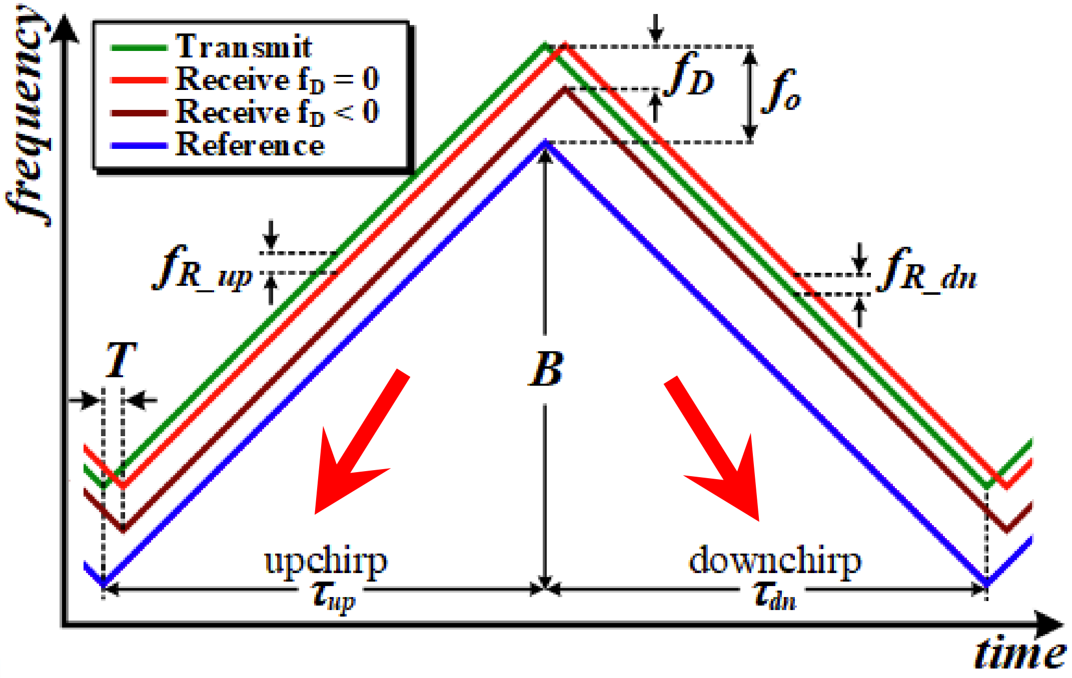
RSL

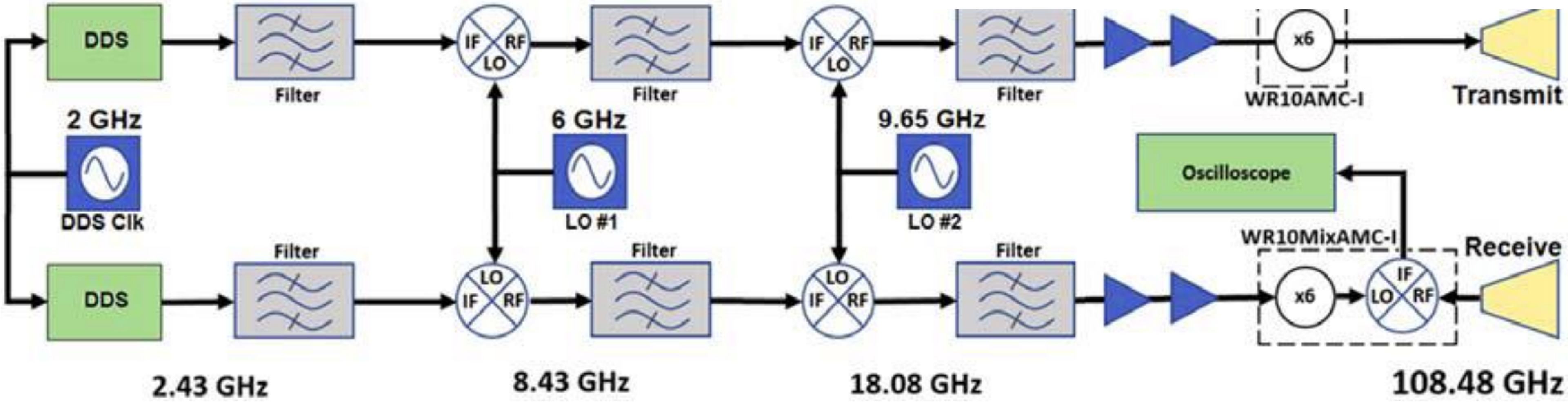
System Description

- Dual DDS waveform generation
  - synchronously clocked and triggered



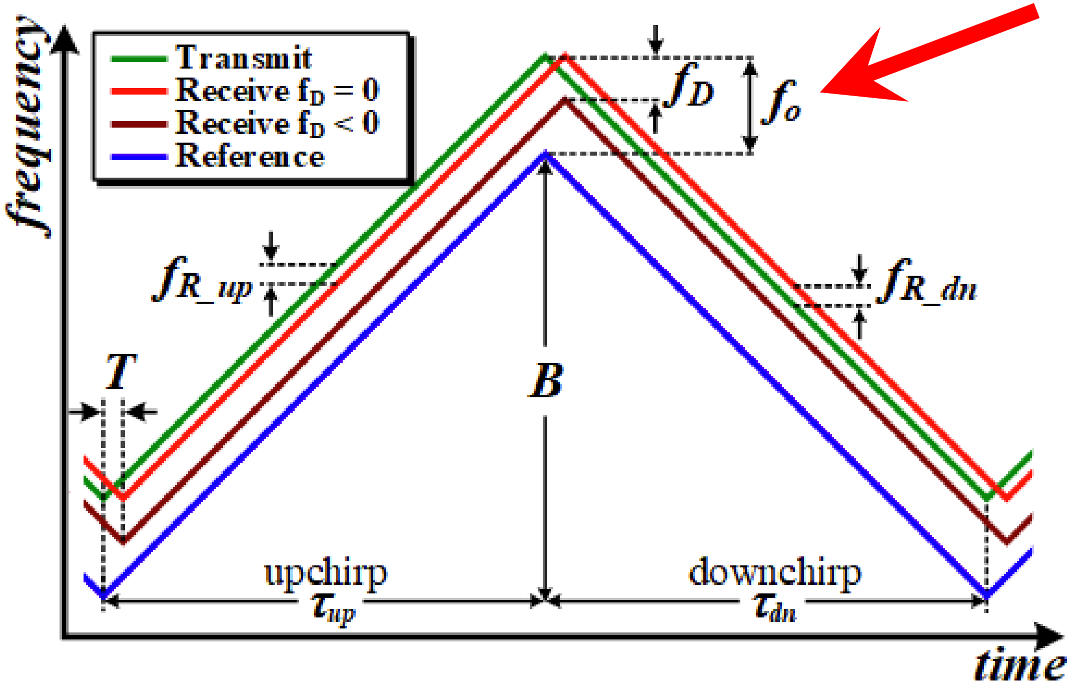
- Dual DDS waveform generation
  - synchronously clocked and triggered
  - 500-μs upchirp and downchirp

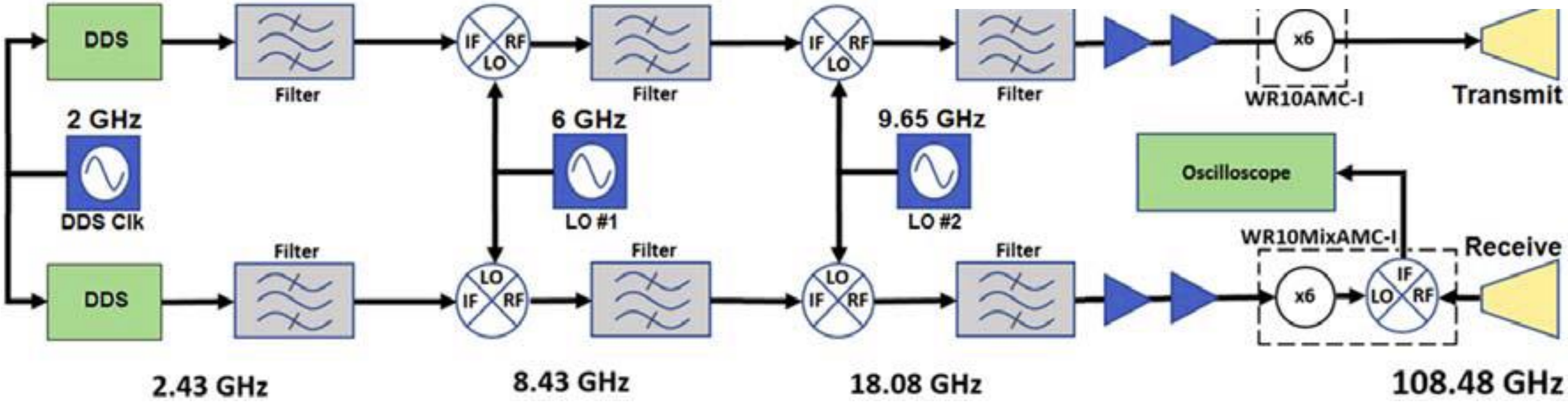




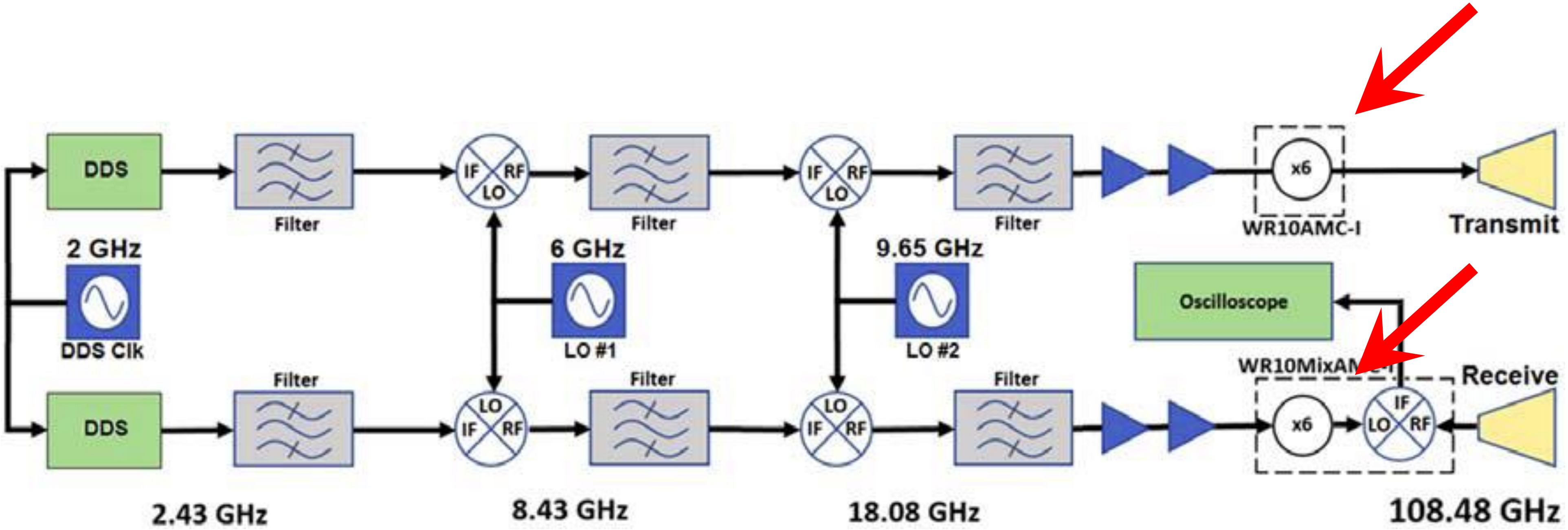
System Description

- Dual DDS waveform generation
  - synchronously clocked and triggered
  - 500-µs upchirp and downchirp
  - offset Tx and Reference frequencies produce 3 MHz f_o heterodyne IF



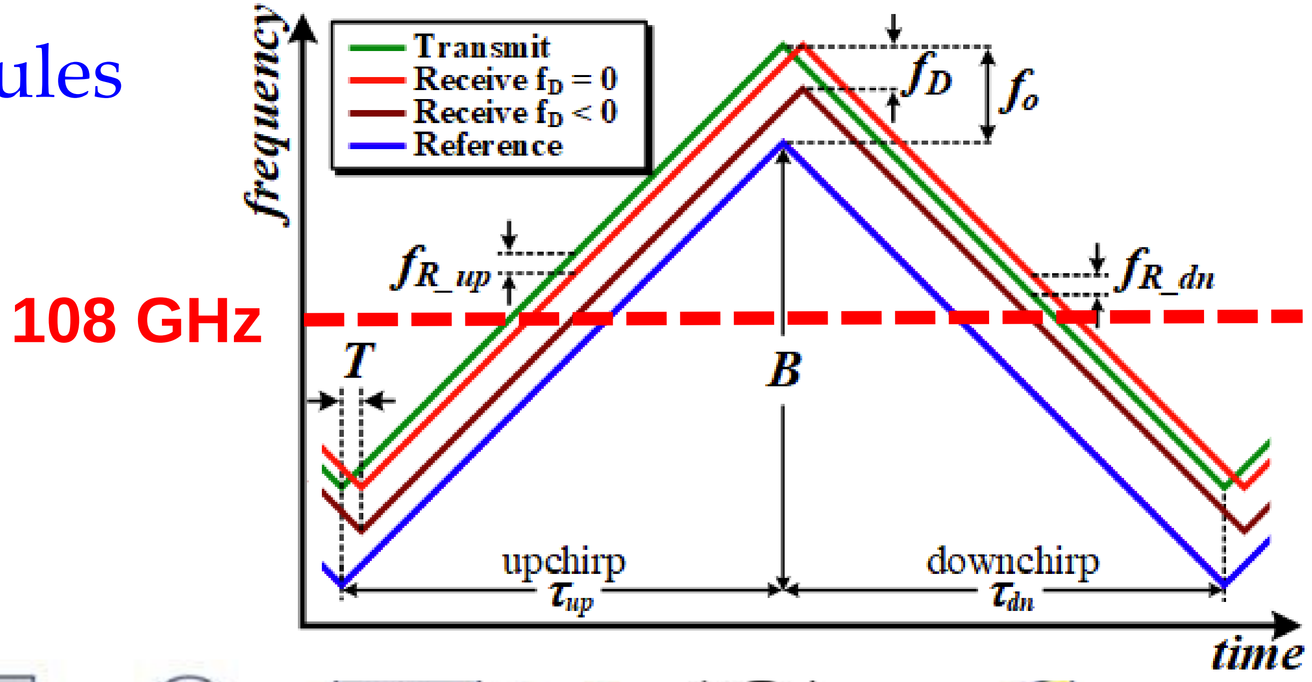


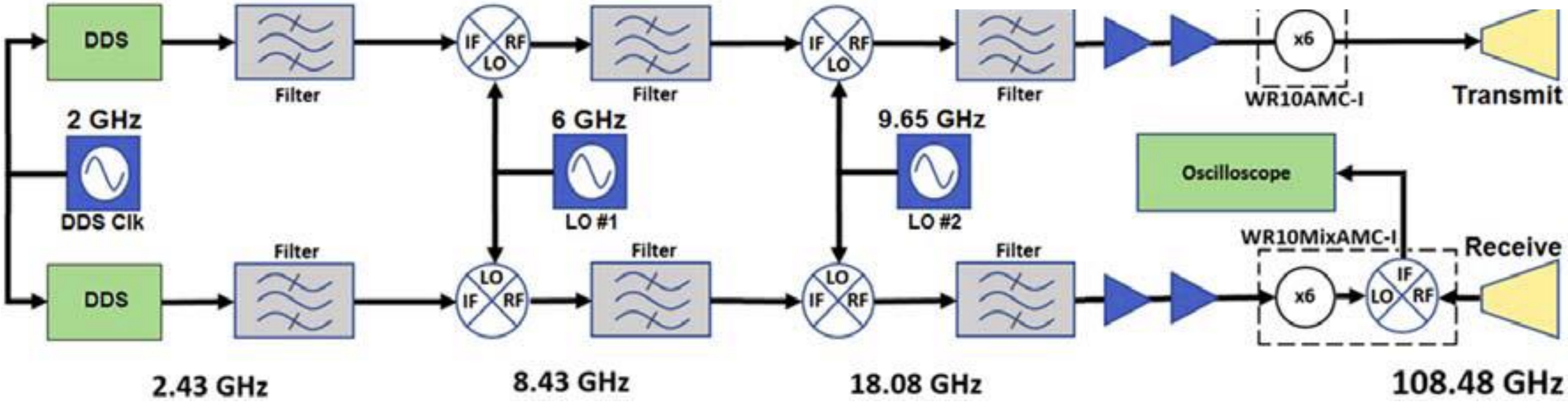
- Virginia Diodes W-band modules
  - ×6 freq mult



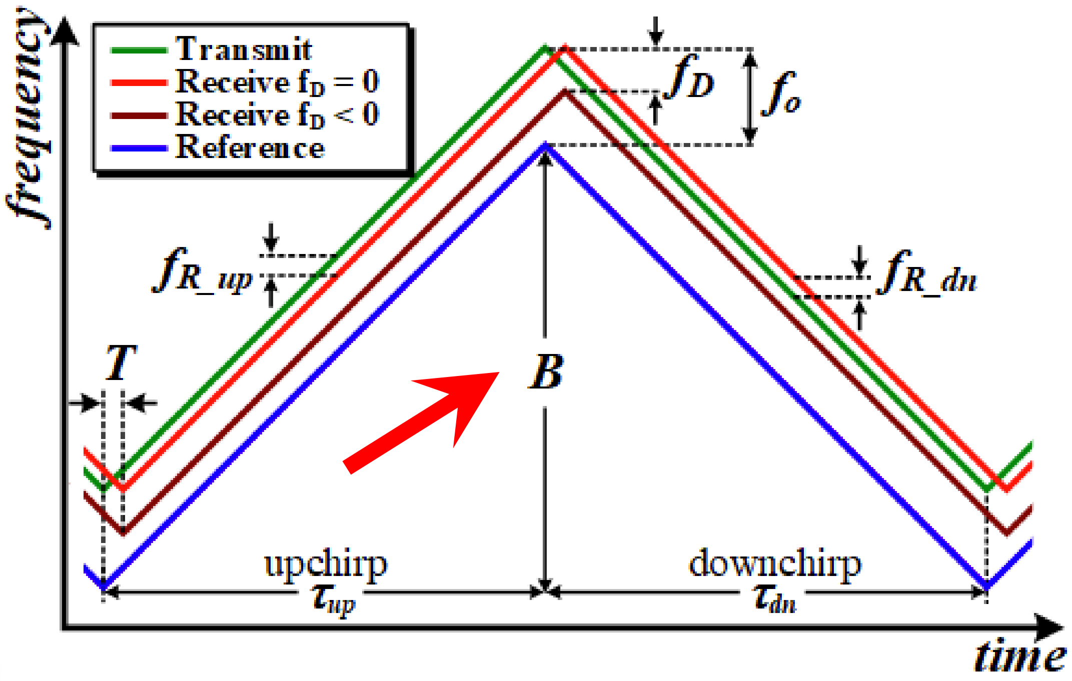
System Description

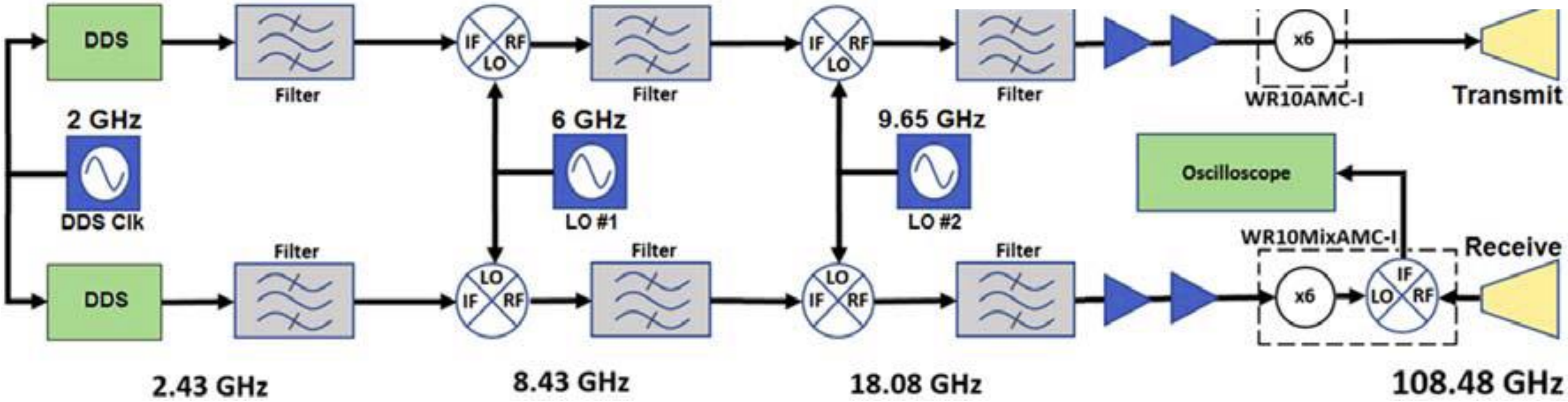
- Virginia Diodes W-band modules
  - ×6 freq mult
  - 108 GHz center frequency





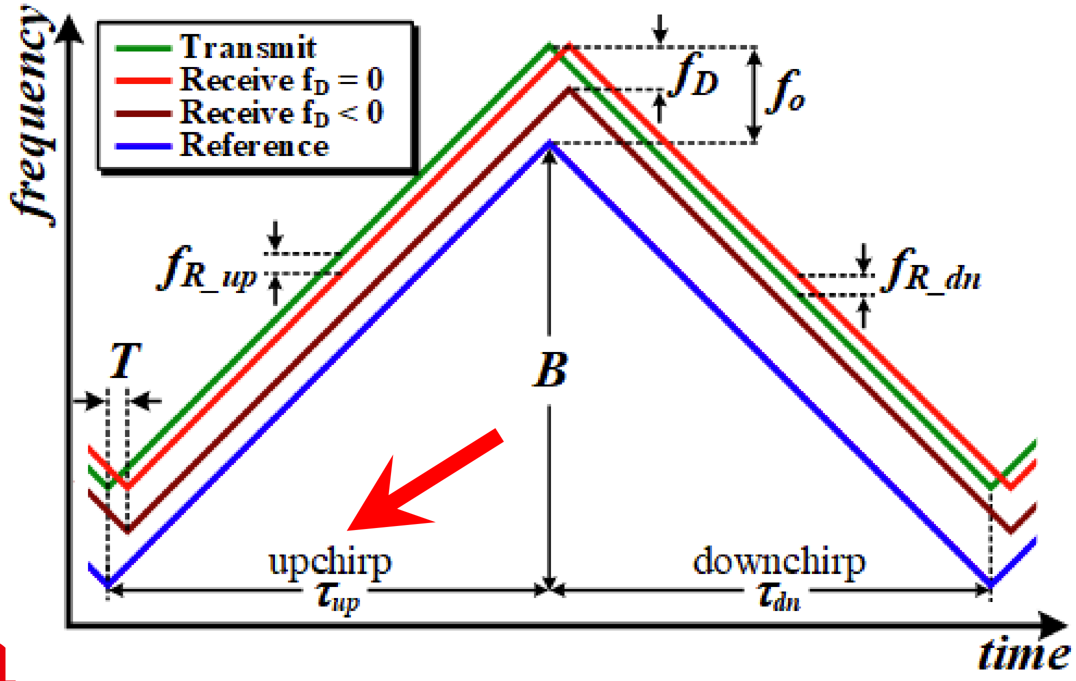
- Virginia Diodes W-band modules
  - ×6 freq mult
  - 108 GHz center frequency
  - 600 MHz chirp bandwidth, ***B***

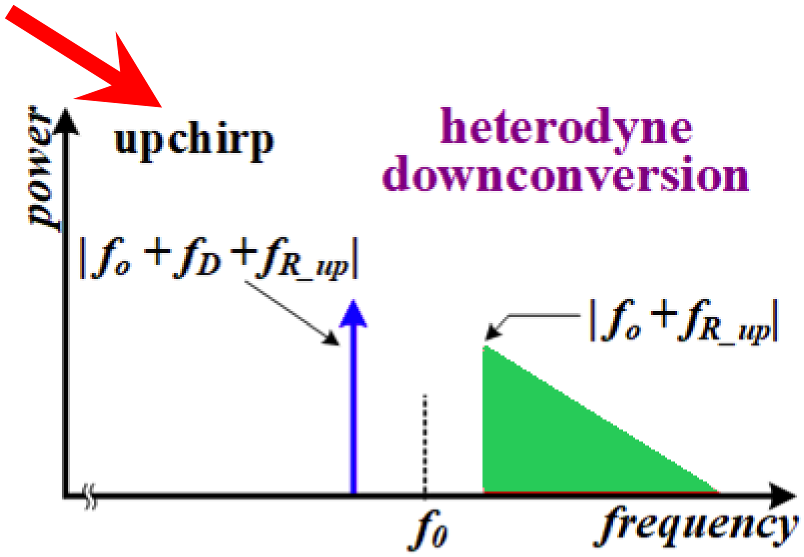




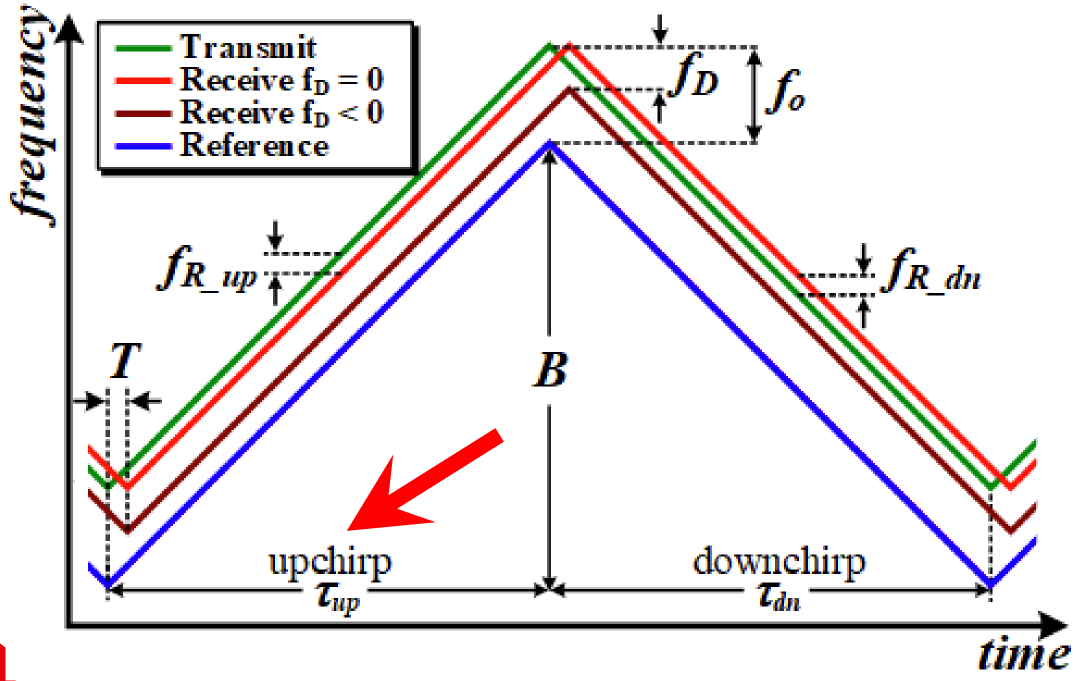
System Description

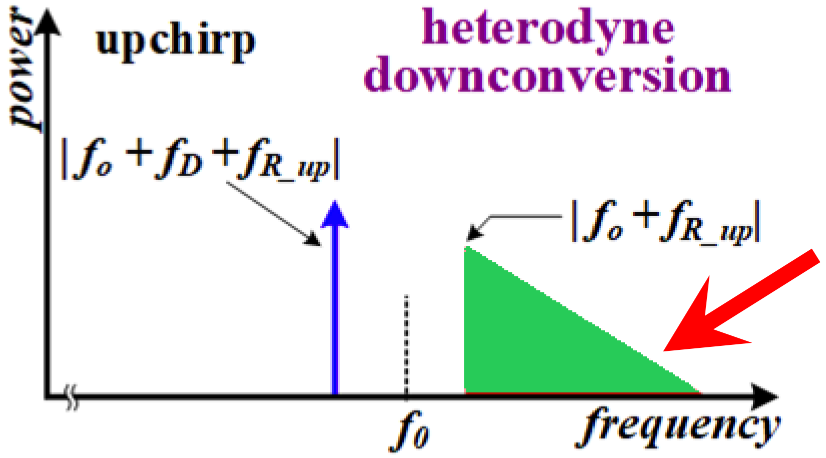
- Spectra expected for upchirp Tx



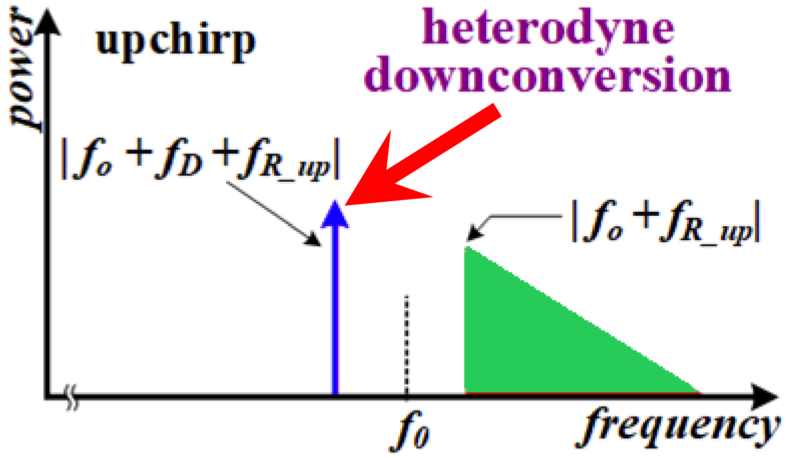


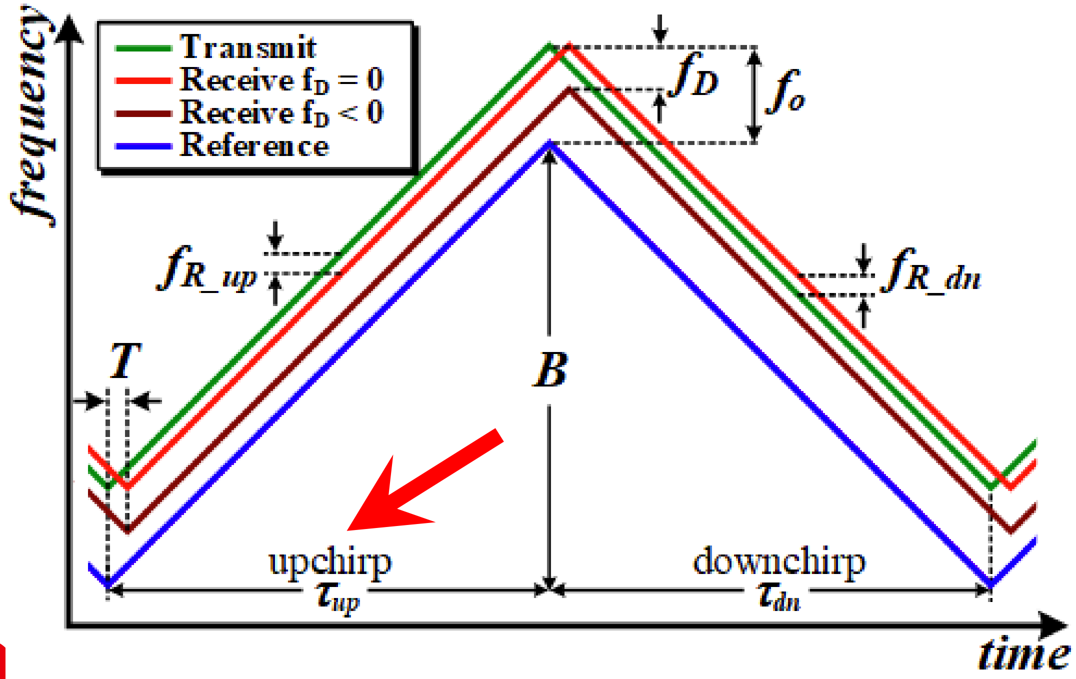
- Spectra expected for upchirp Tx
  - static clutter





- Spectra expected for upchirp Tx
  - static clutter
  - fast-moving object (moving away from radar)

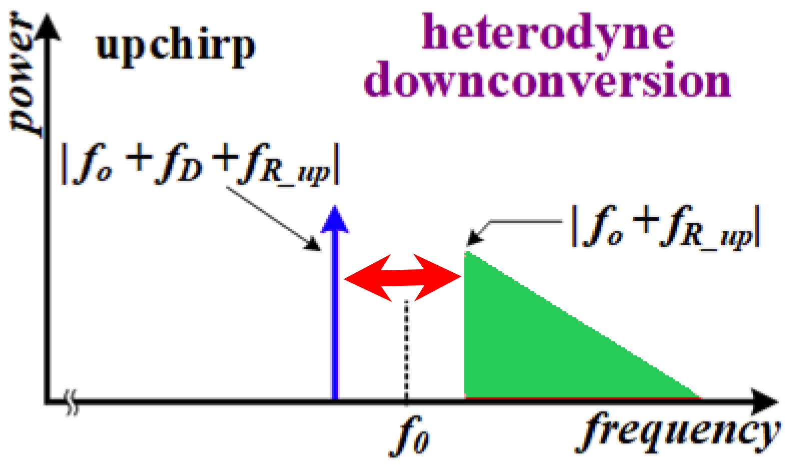


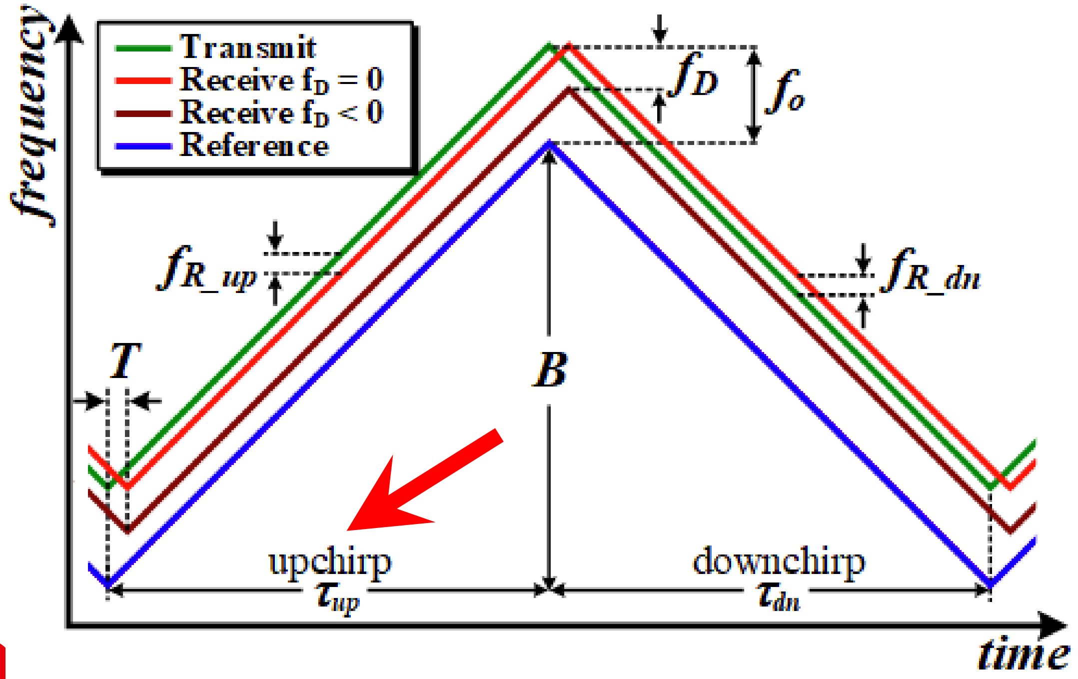


System Description

- Spectra expected for upchirp Tx
  - static clutter
  - fast-moving object (moving away from radar)

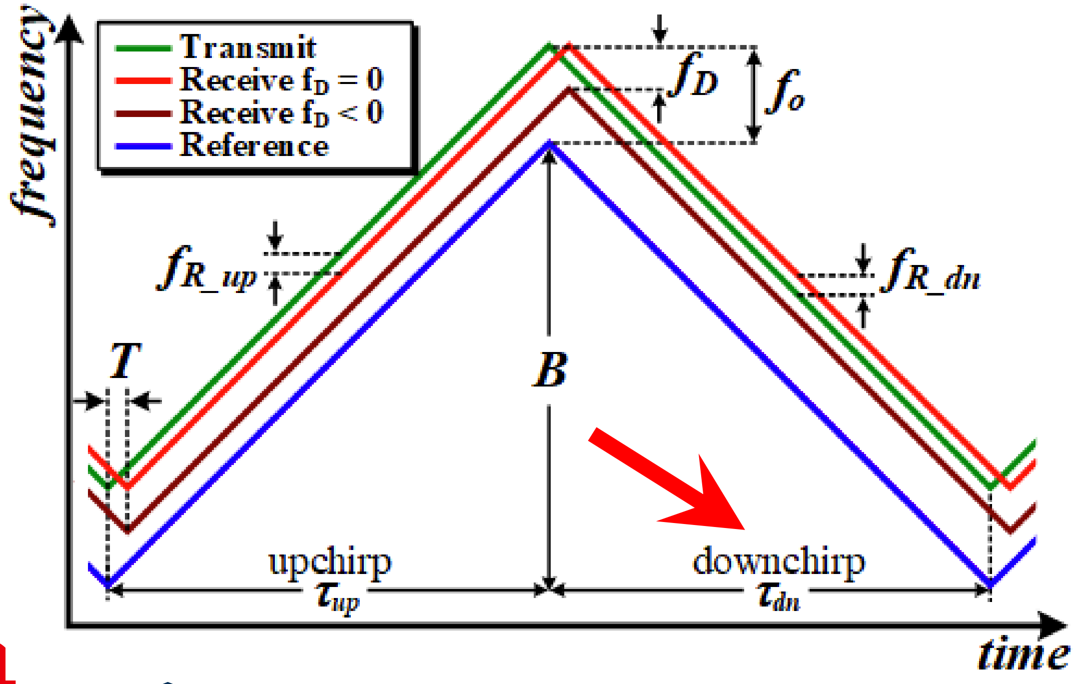
  Note the spectral separation

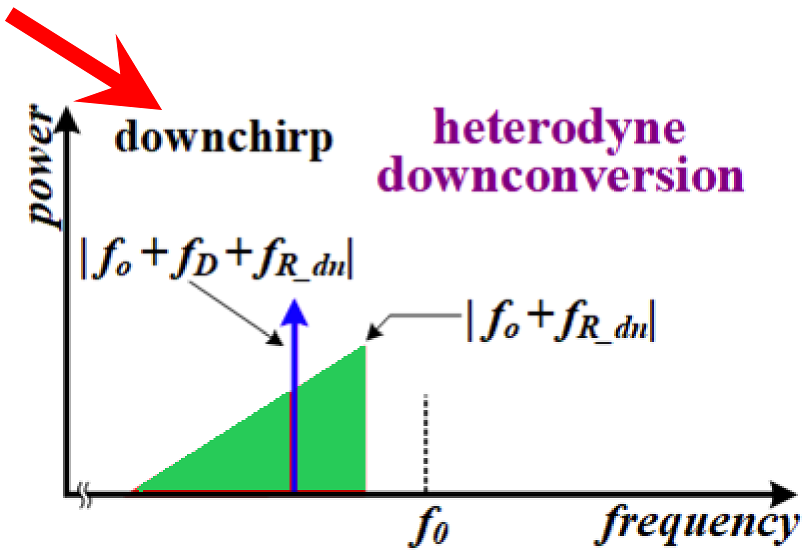




System Description

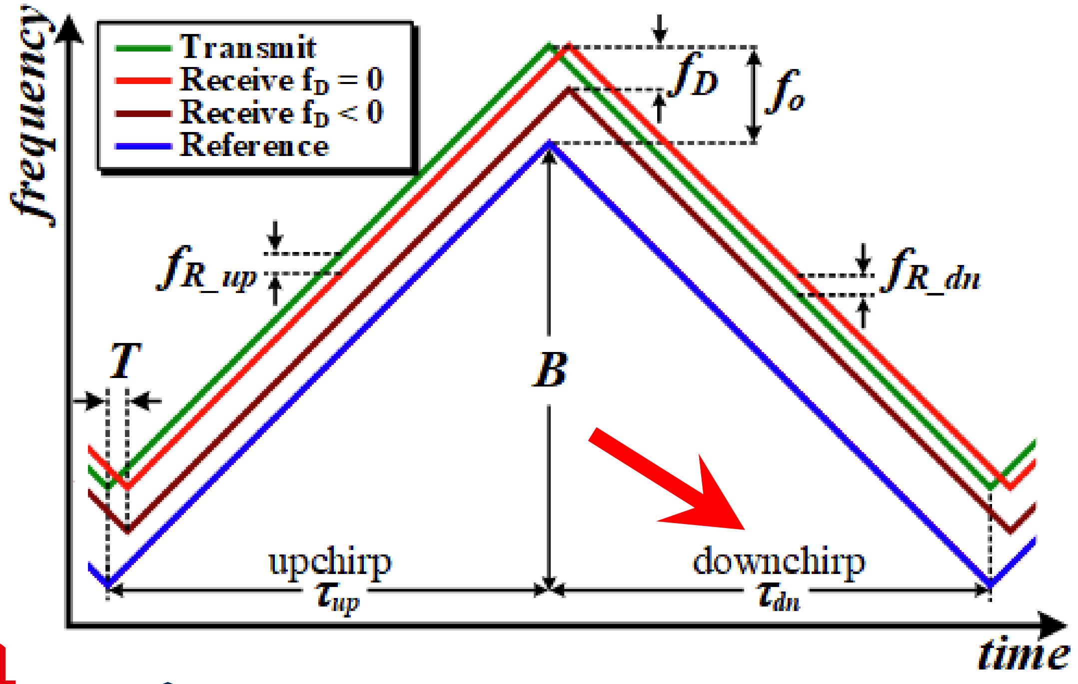
- Spectra expected for downchirp Tx

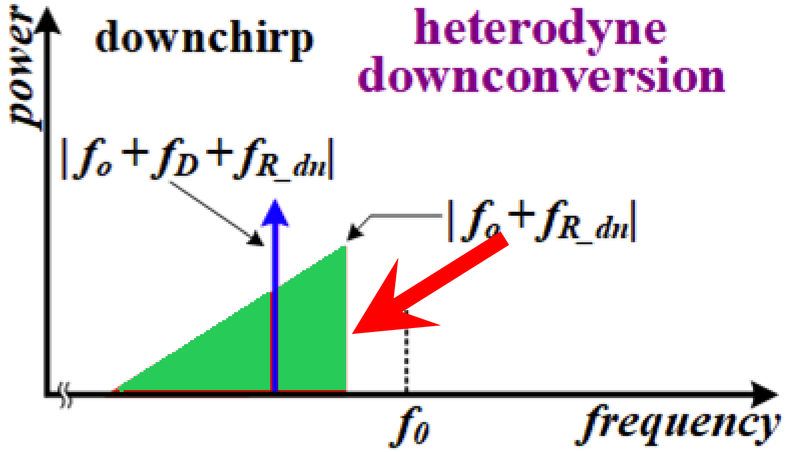




System Description

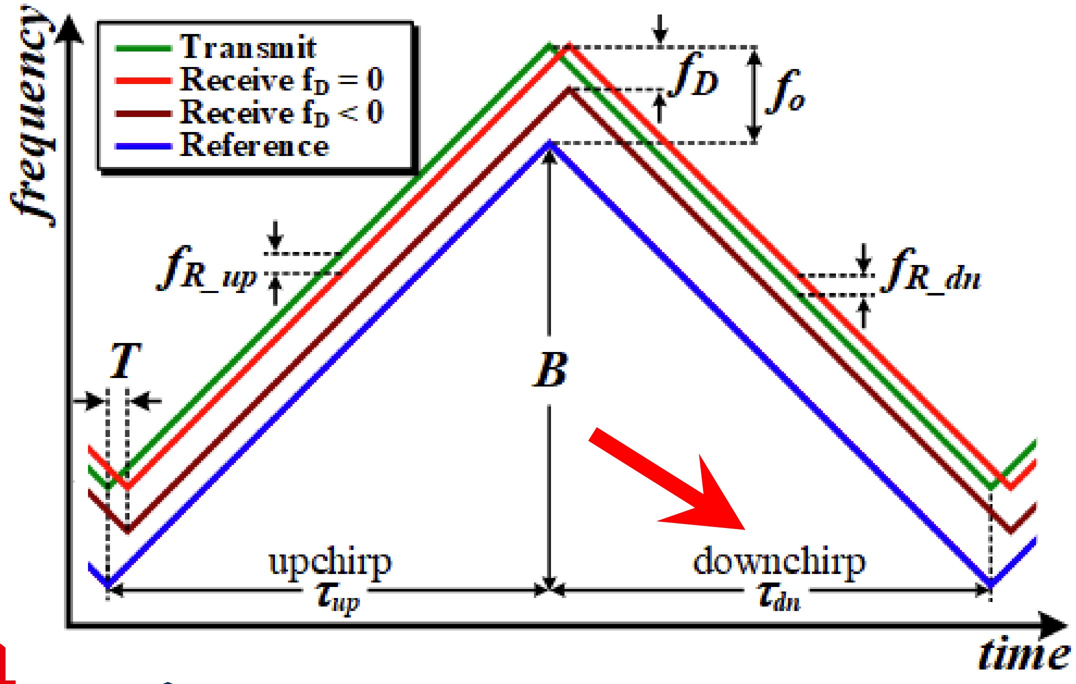
- Spectra expected for downchirp Tx
  - static clutter (mirrored about $\boldsymbol{f_o}$)

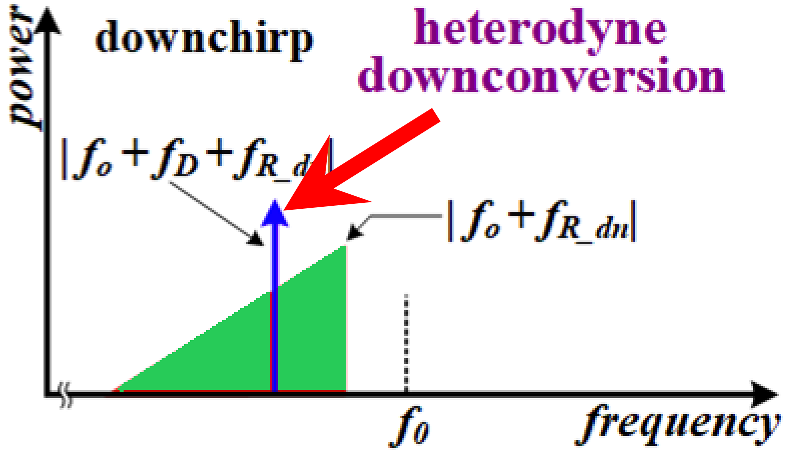




System Description

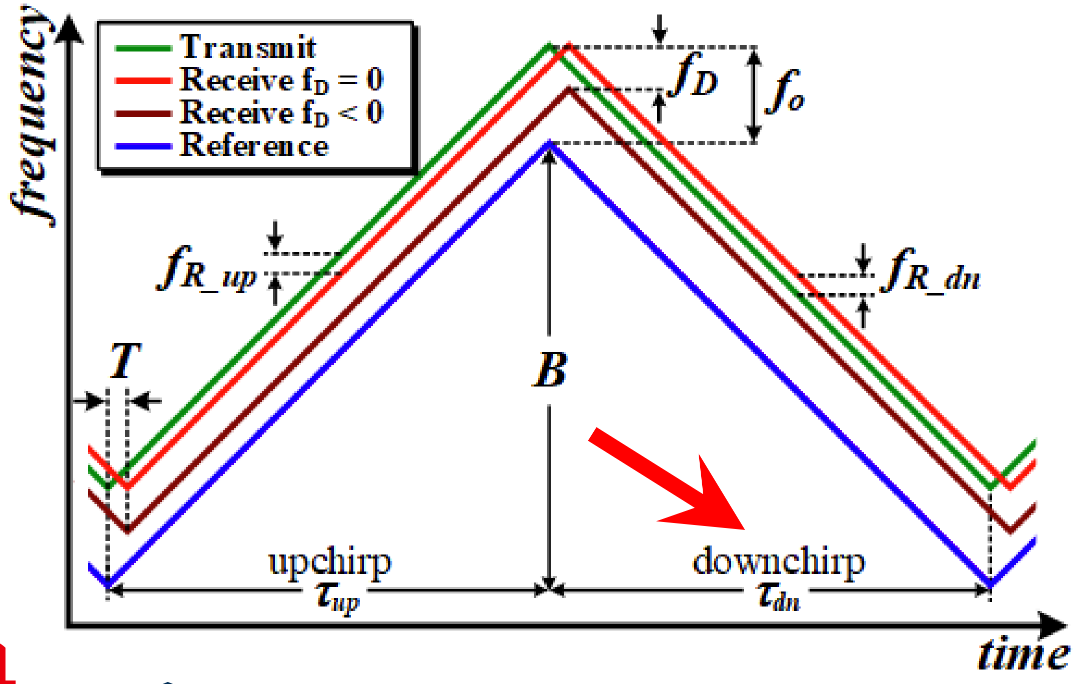
- Spectra expected for downchirp Tx
  - static clutter
  - fast-moving object (moving away from radar) assumes $f_D >> f_R$

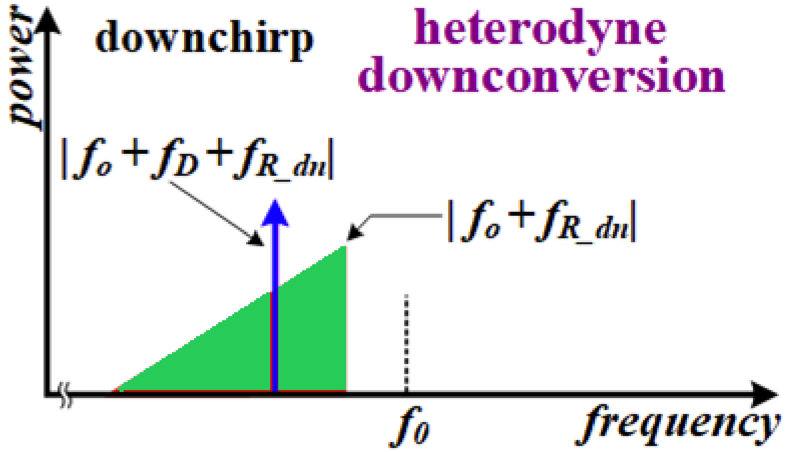




- Spectra expected for downchirp Tx
  - static clutter
  - fast-moving object (moving away from radar)

Note the <u>lack</u> of spectral separation

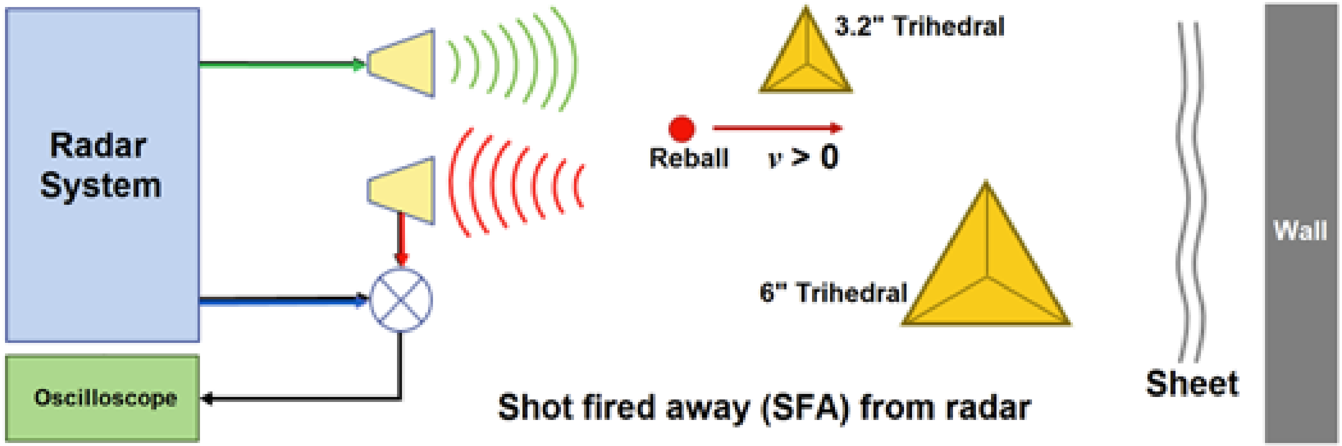




Test Setup and Measurement Results

- Tested in an unoccupied auditorium **(clutter-rich environment)**
- Paintball serves as fast-moving object **(v ≈ 90 m/s)**

mm-wave radar



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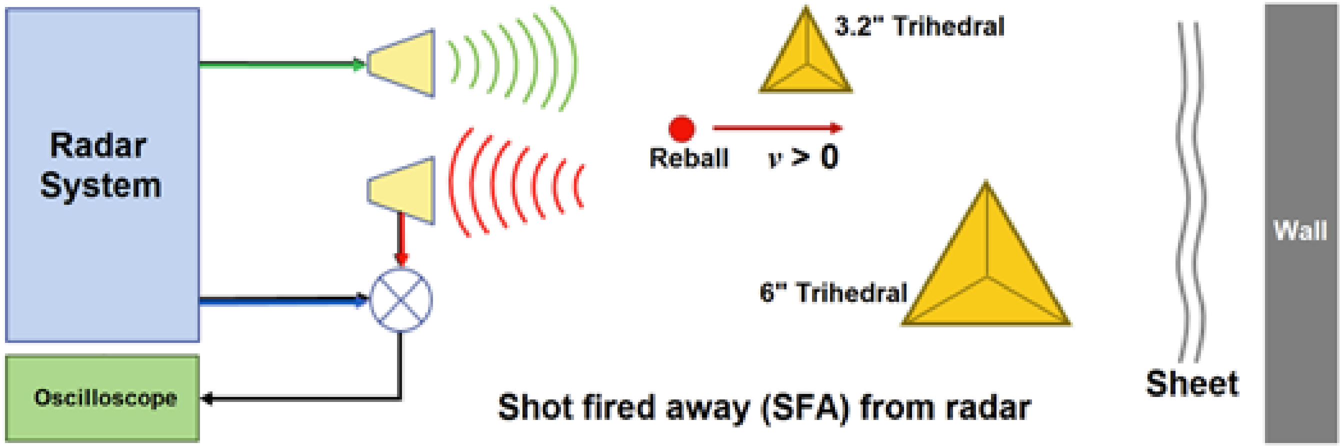
- Paintball serves as fast-moving object (v ≈ 90 m/s)
- Paintball **(actually a solid rubber *0.68″ reball*)** fired away from the radar
- Fabric sheet safely absorbs paintball’s energy

Before impact

After impact



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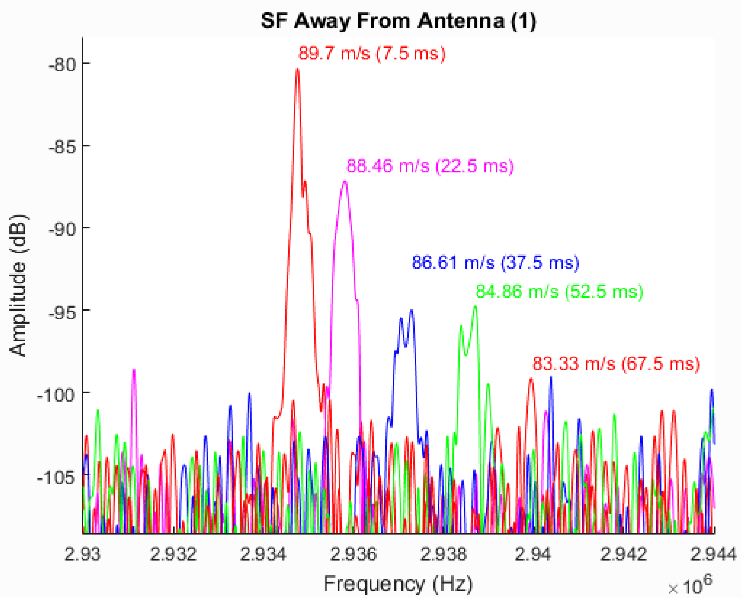
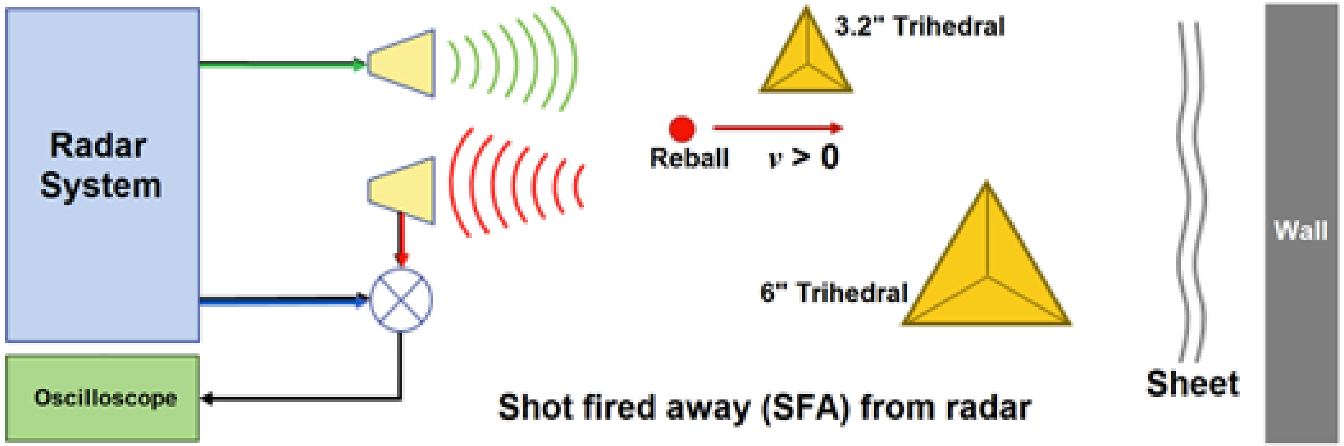
- Paintball serves as fast-moving object (v ≈ 90 m/s)
- Paintball **(actually a solid rubber *0.68″ reball*)** fired away from the radar
- Fabric sheet safely absorbs paintball’s energy
- Oscilloscope captures radar output **(triggered by reball launch)**

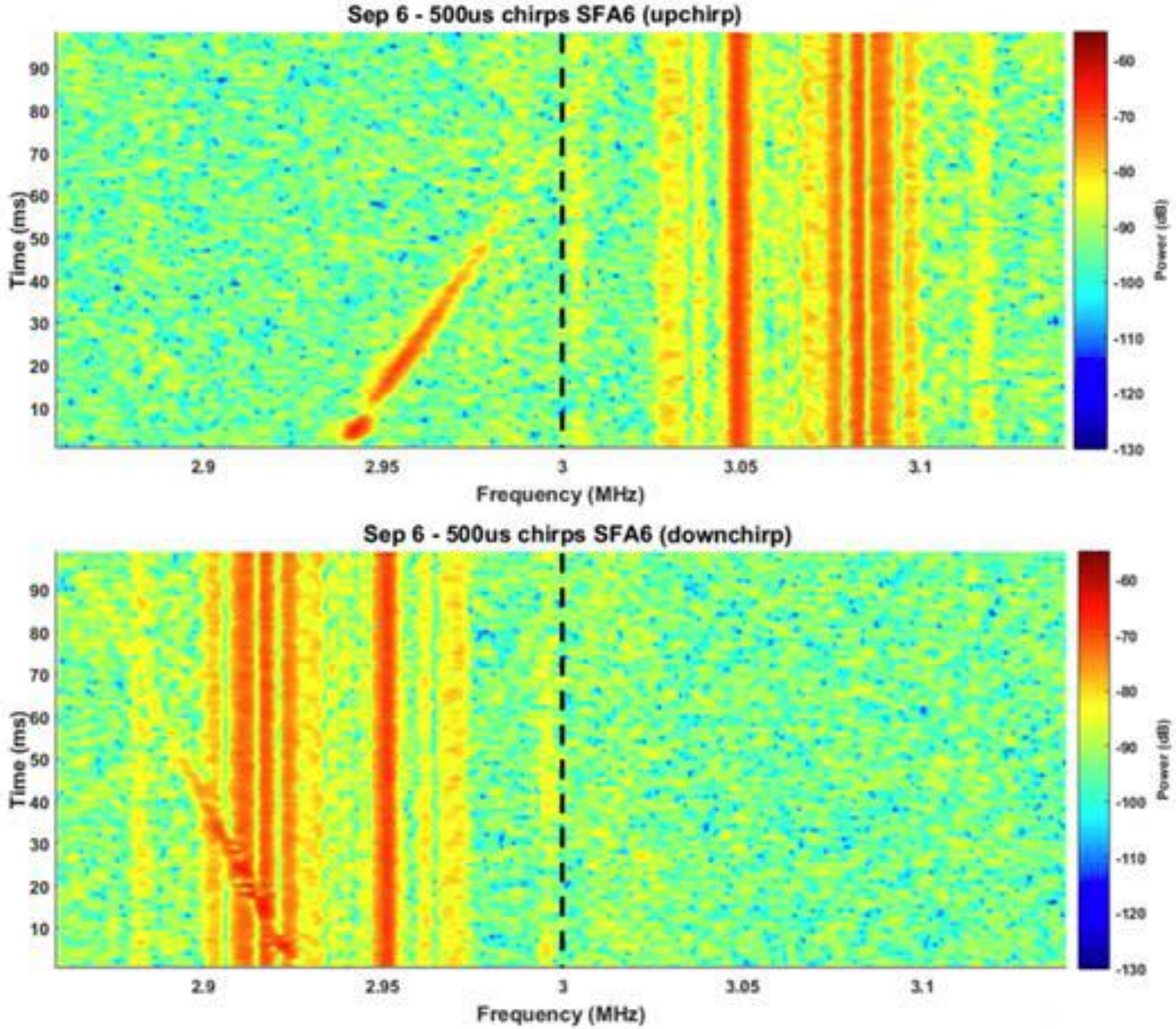




Test Setup and Measurement Results

Measured echograms

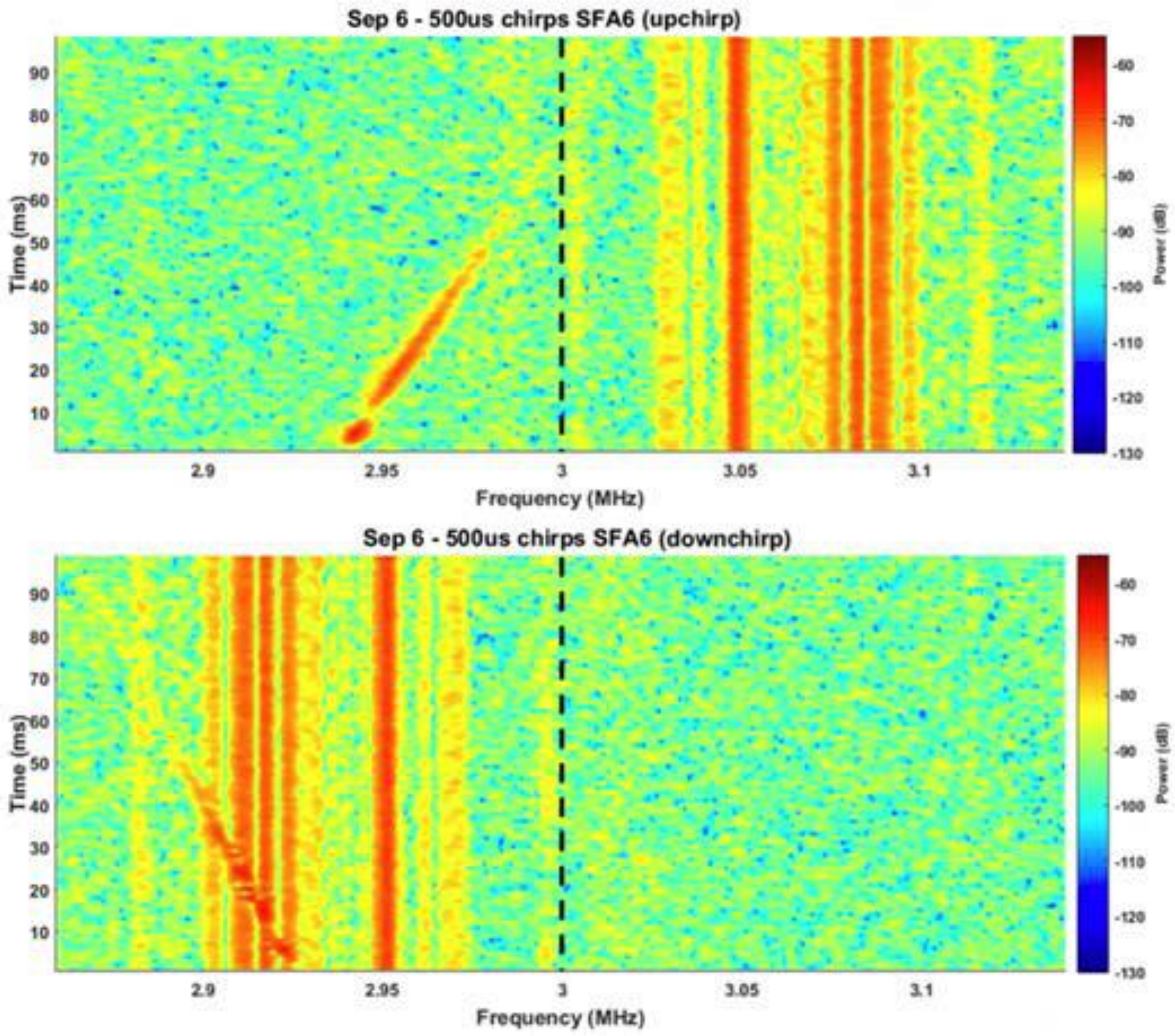
- Shot fired away from the radar **(SFA)**
- Spectral separation in upchirp data



Test Setup and Measurement Results

Measured echograms

- <u>Shot fired away</u> from the radar **(SFA)**
- Spectral separation in upchirp data
- Spectral overlap in downchirp data



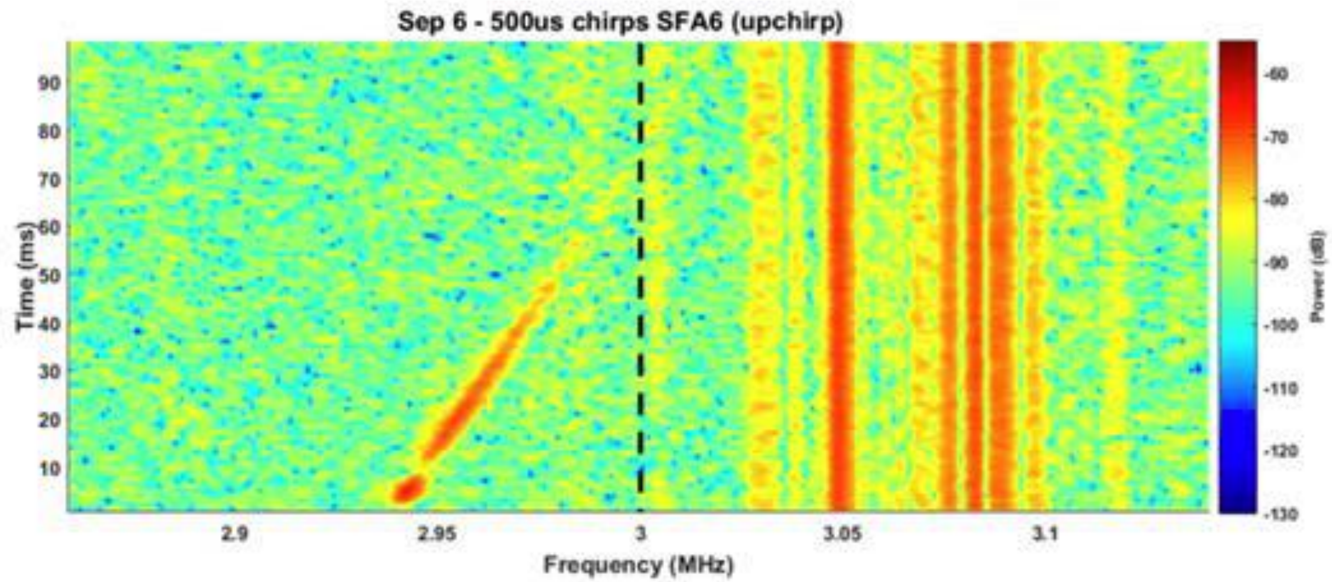
Test Setup and Measurement Results

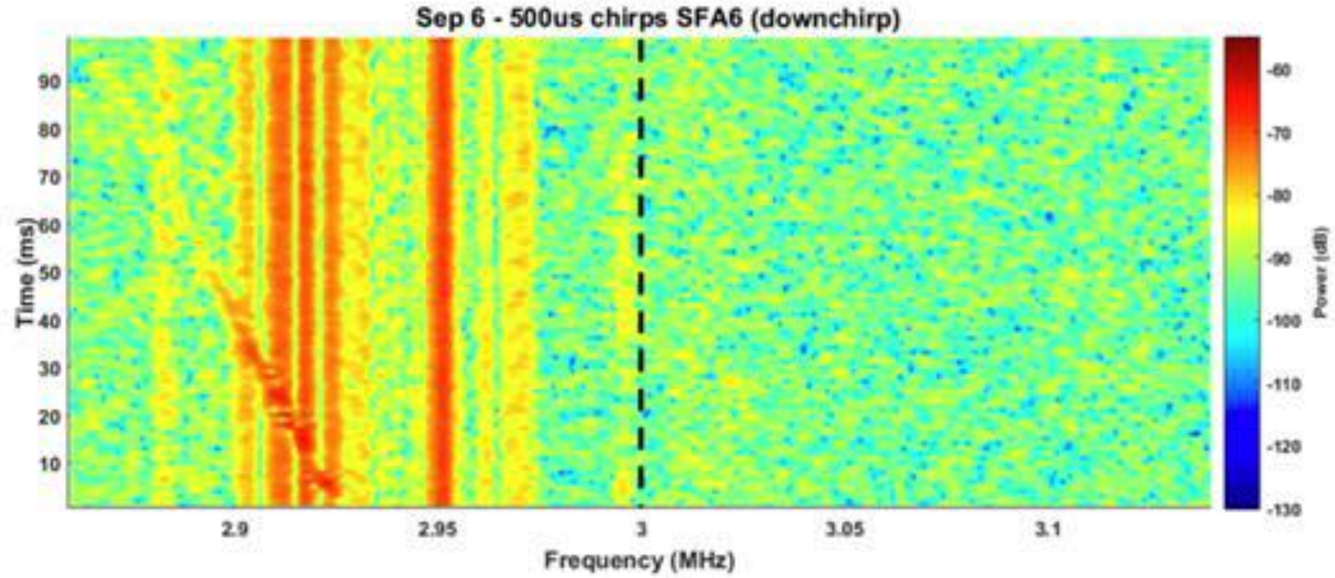
Measured echograms

- <u>Shot fired away</u> from the radar **(SFA)**
- Spectral separation in upchirp data
- Spectral overlap in downchirp data

- Need data from both upchirp and downchirp to unambiguously estimate of reball's range and Doppler

- Hence need for clutter suppression

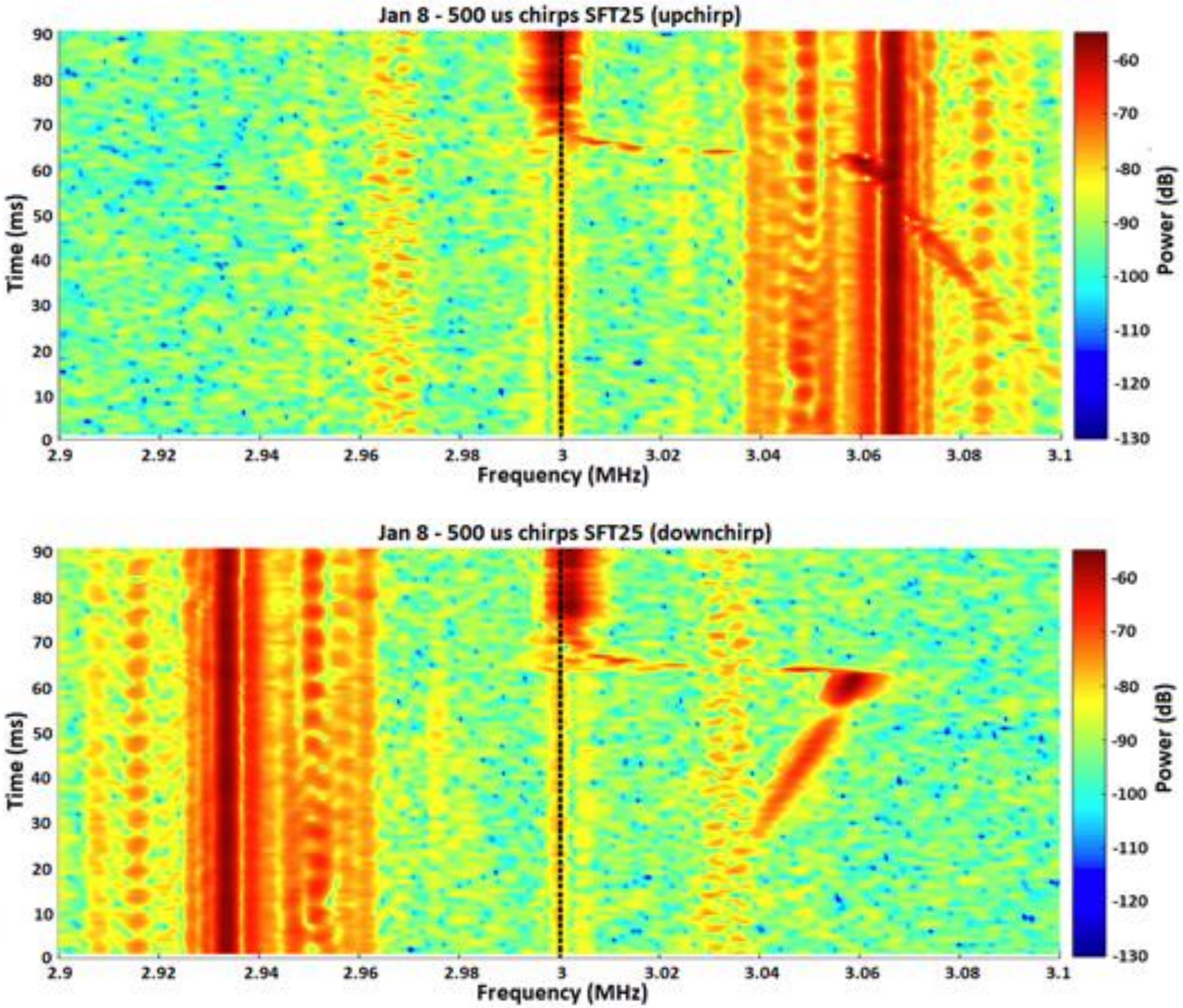




Test Setup and Measurement Results

Measured echograms

- <u>Shot fired toward</u> the radar **(SFT)**
- Spectral overlap in upchirp data



Test Setup and Measurement Results

Measured echograms

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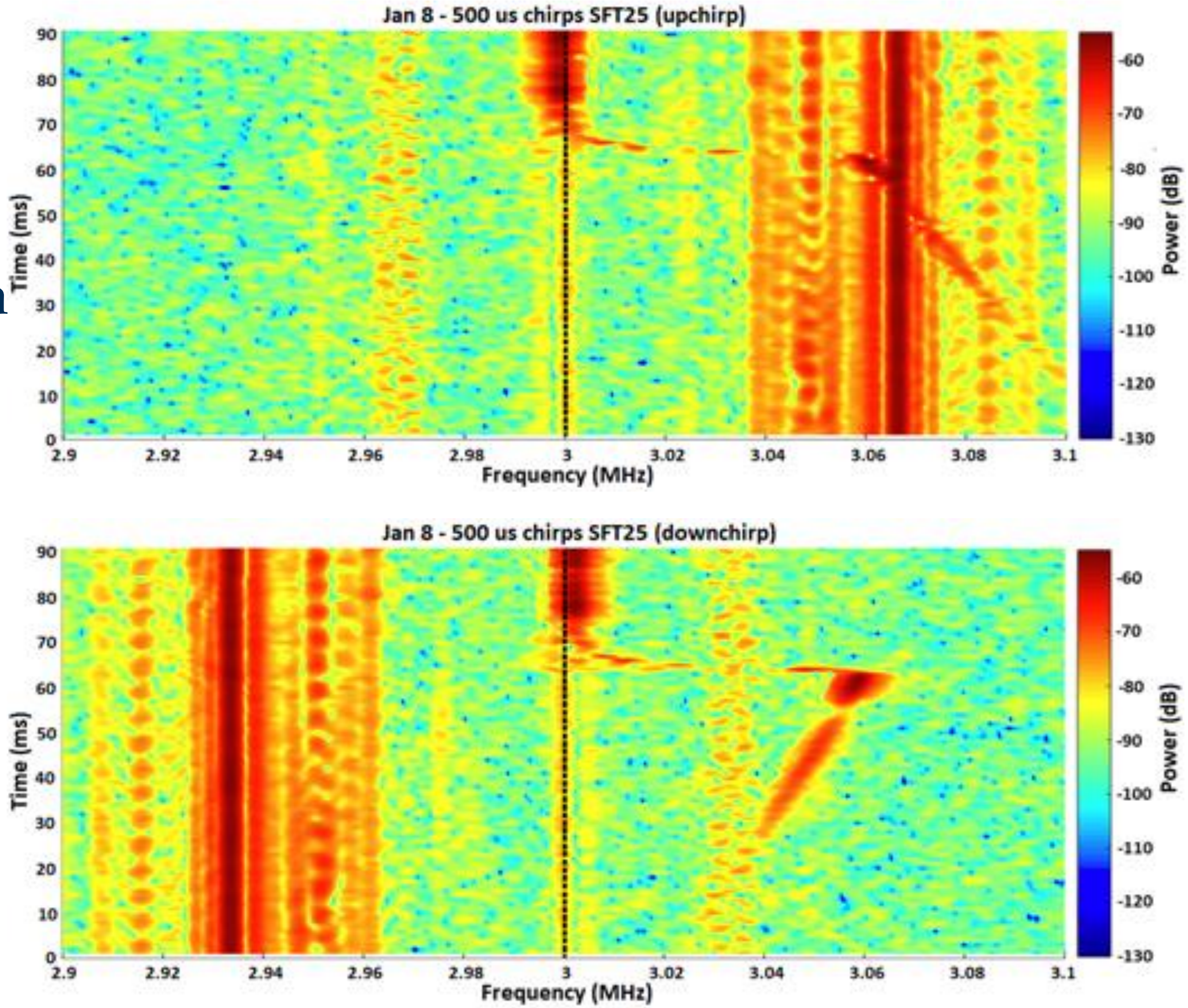

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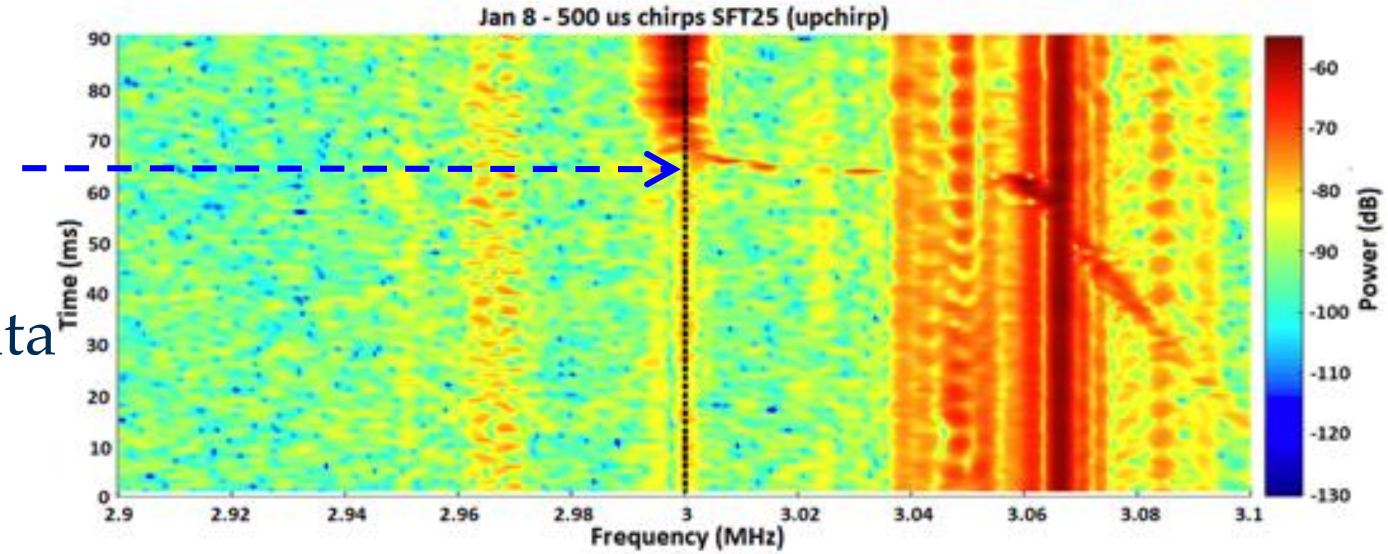
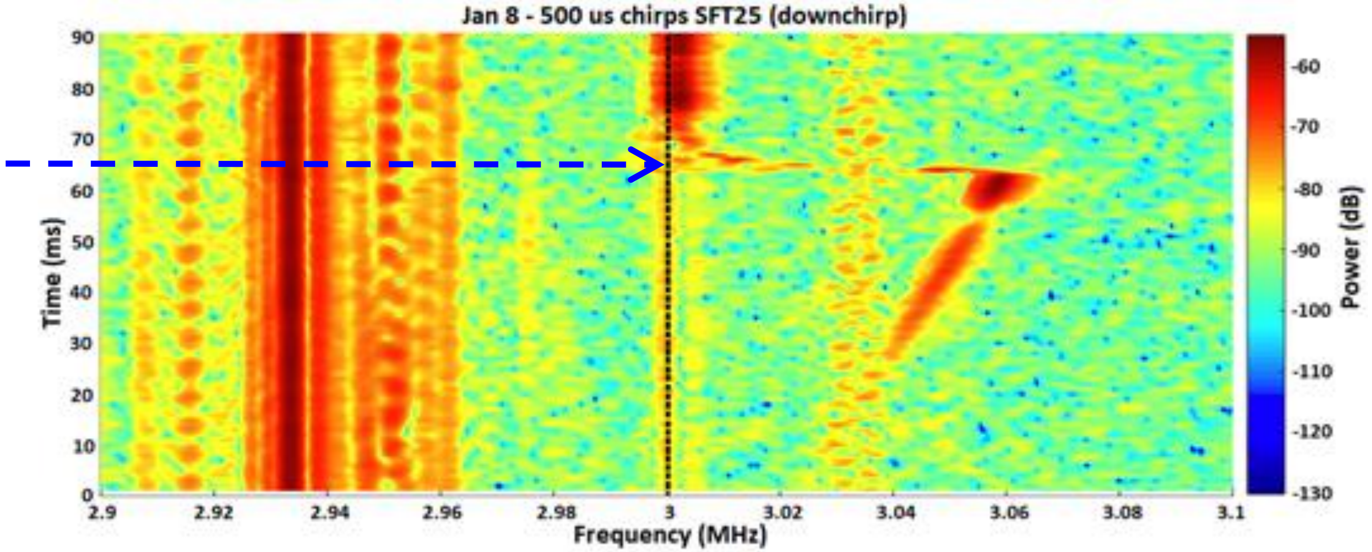


- Note that about 65 ms into the measurement there is an abrupt change in the spectrogram.



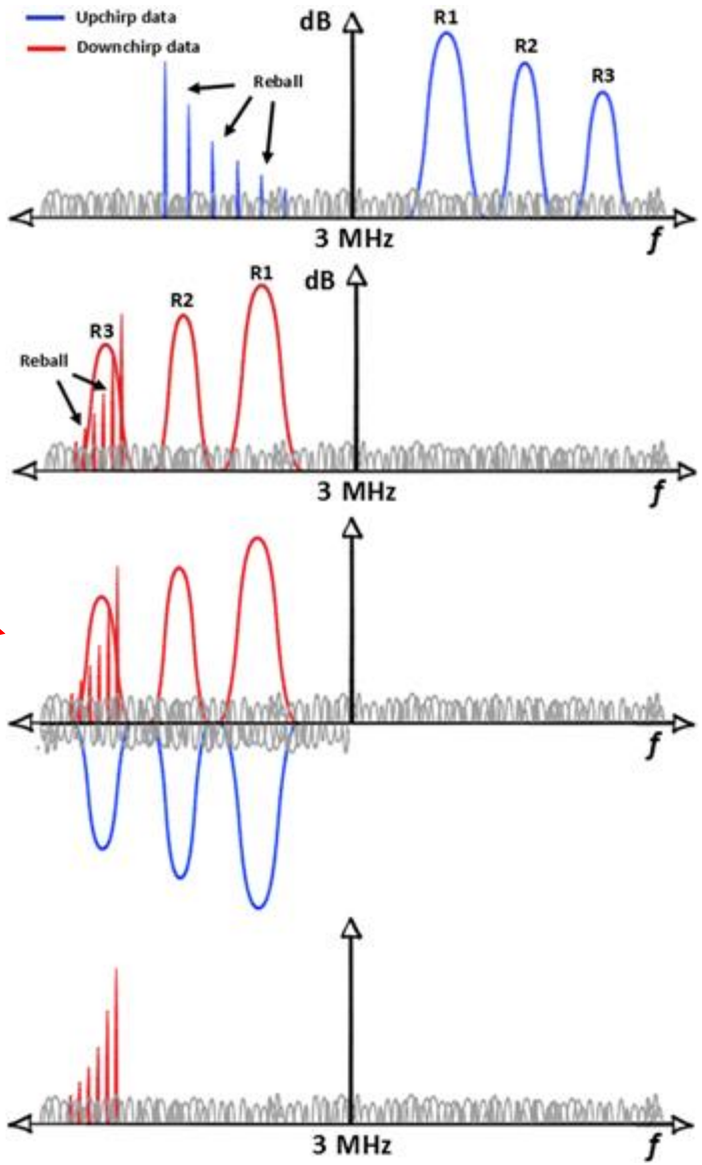
- This corresponds to the instant the reball impacts the sheet.

Clutter Suppression for Fast-Moving Objects

"fold-and-subtract" clutter suppression

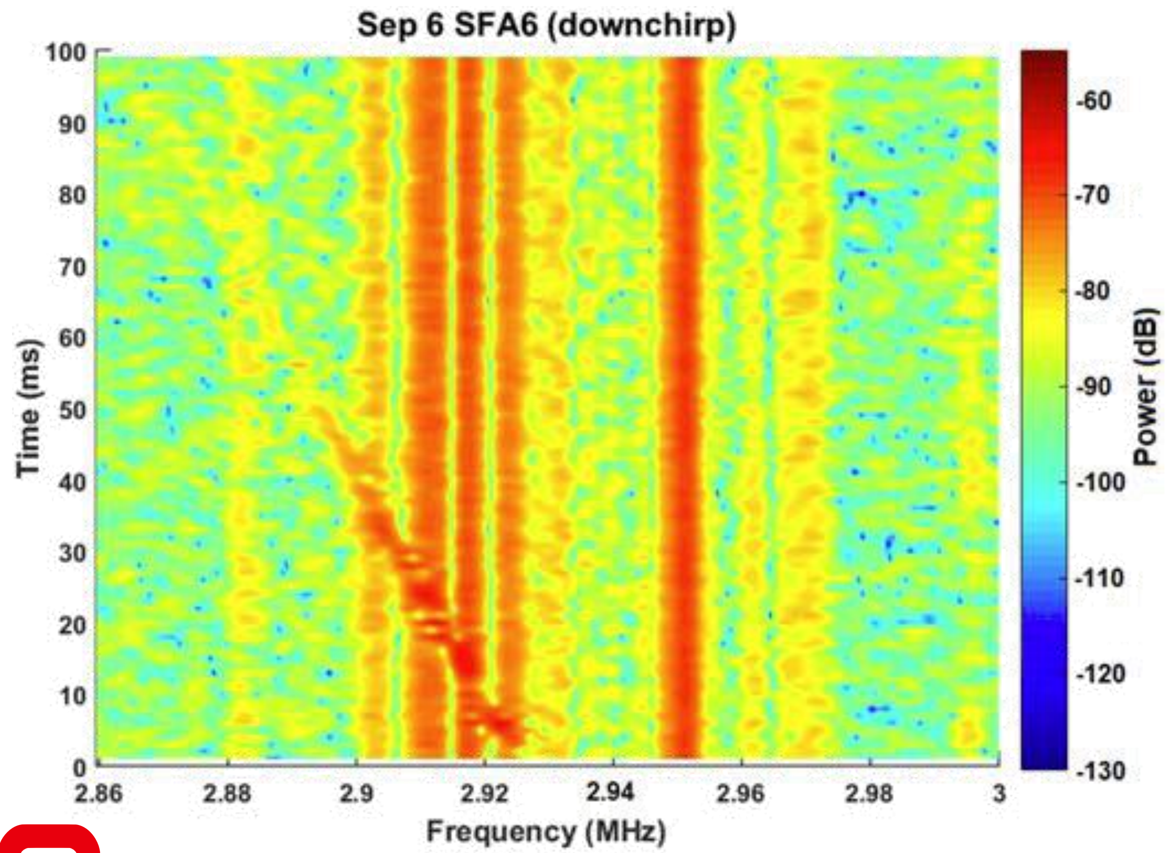
- Clutter's amplitude response from the ***spectral separation*** case is combined with the clutter's phase response from the ***spectral overlap*** case to obtain a complete clutter spectral estimate, which is used to subtract the overlapped clutter.

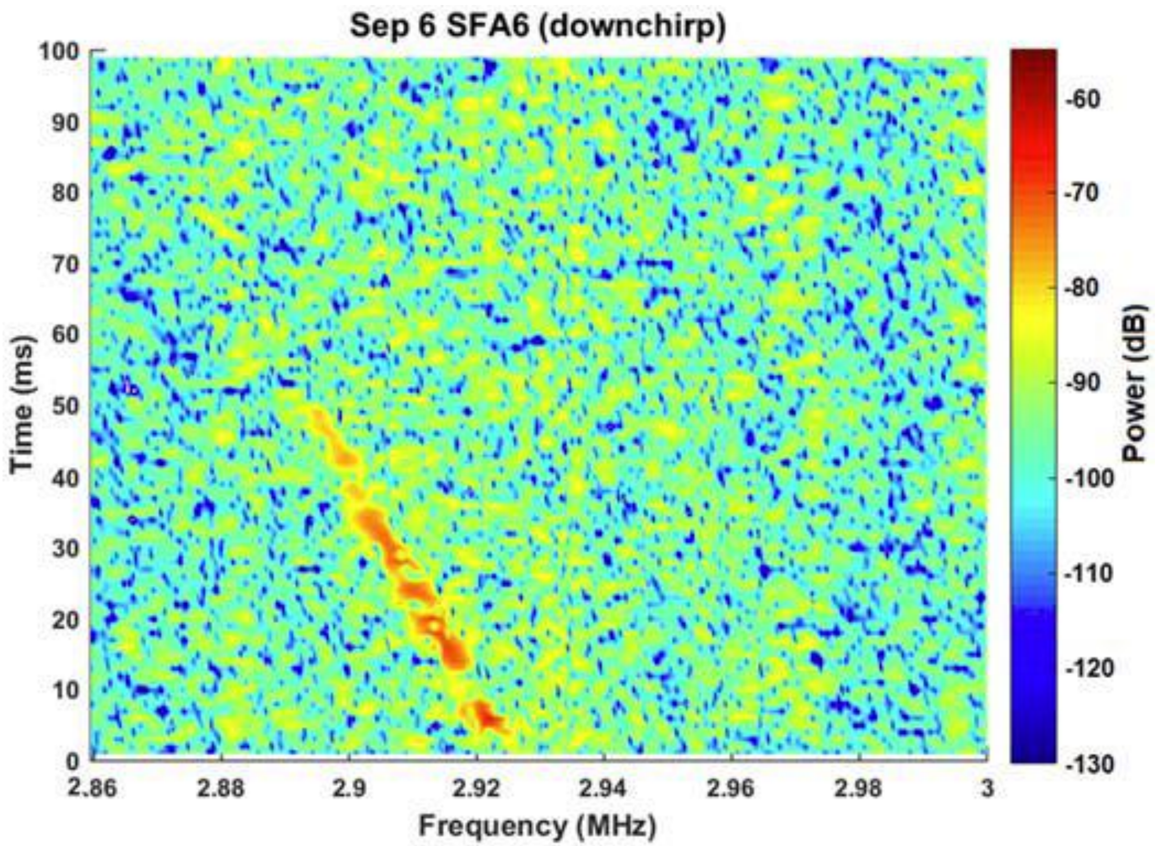
- Performed independently for each fast-time data record composed of upchirp and downchirp spectral data.



Clutter suppression applied to measured "shot fired away (SFA)" data

> 25 dB clutter suppression





Clutter Suppression for Fast-Moving Objects

Clutter suppression applied to measured "shot fired toward (SFT)" data

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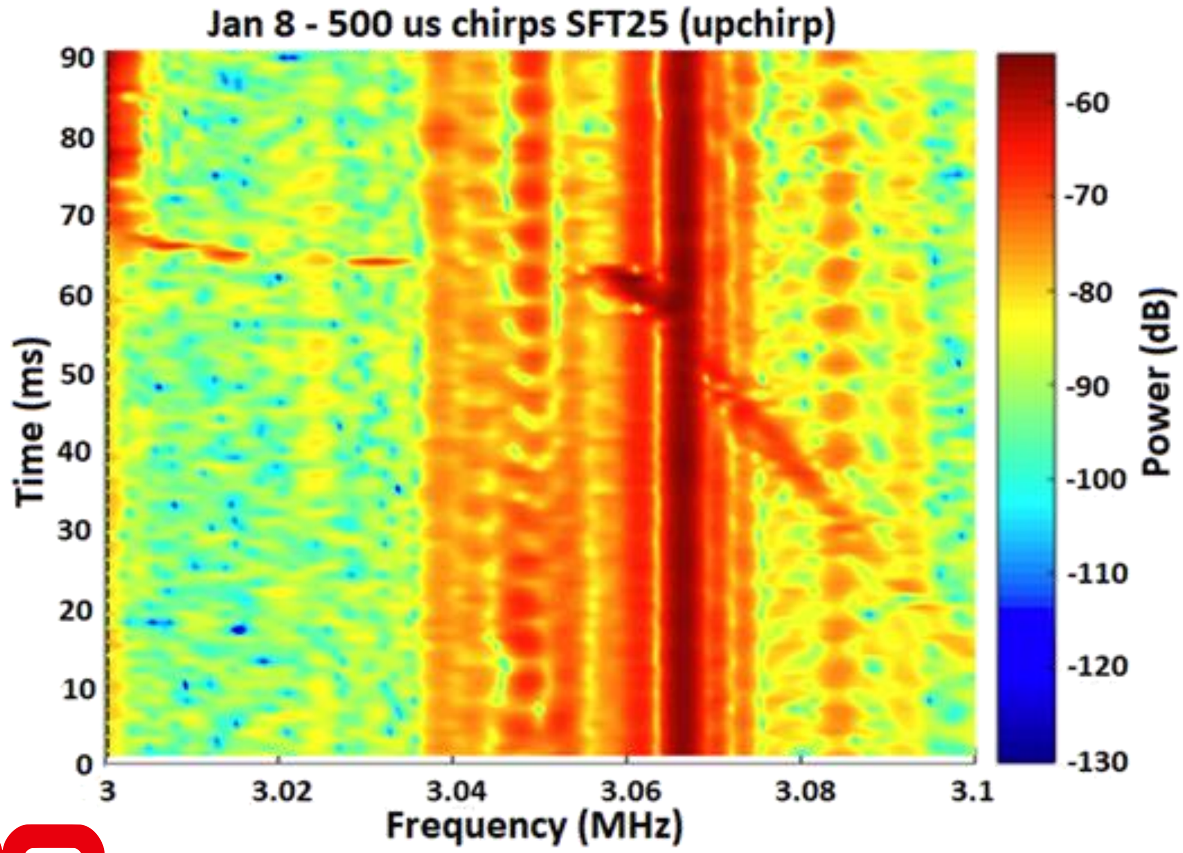

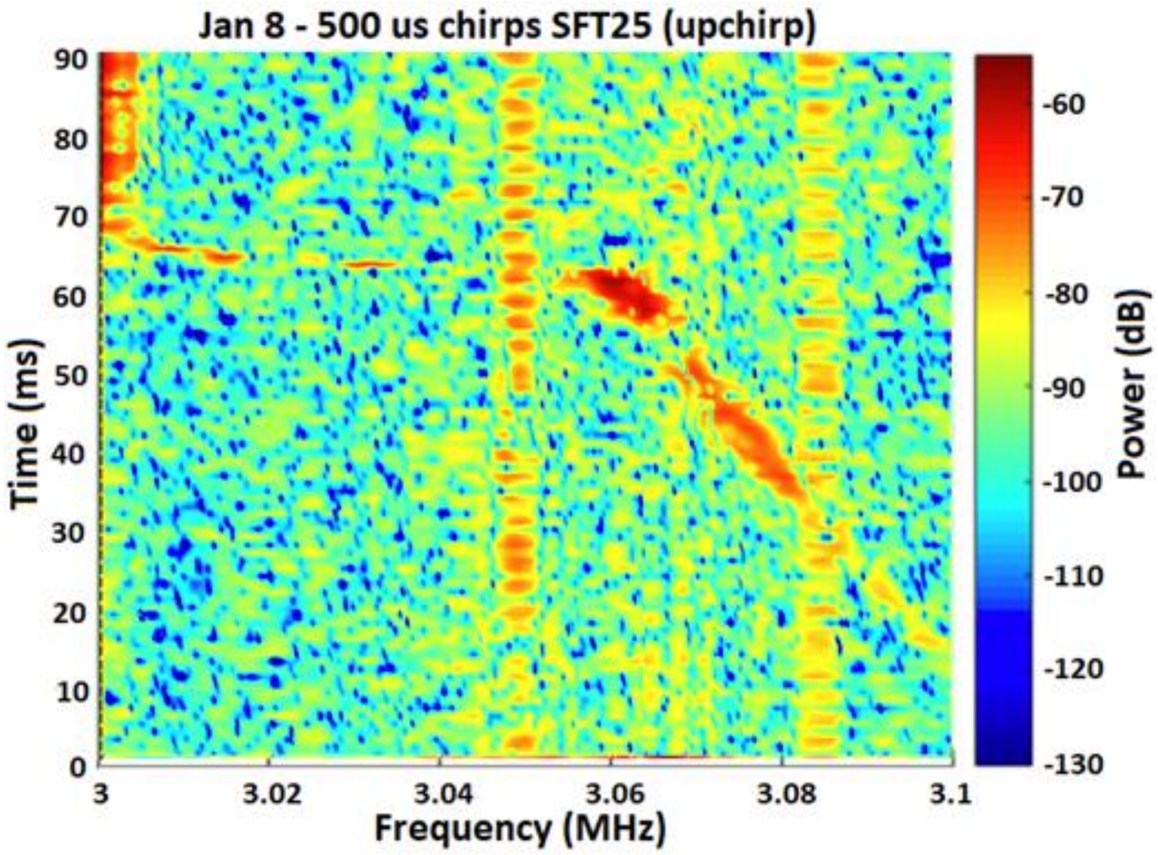

Conclusions

- mm-wave radar data were collected, demonstrating detectability of a 0.68″ reball traveling at 90 m/s at ranges up to about 7 m.
- As expected, clutter obscures the fast-mover's spectral signature during only half of the upchirp / downchirp cycles, providing clean data during the other half.
- Application of "fold-and-subtract" clutter cancellation resulted in > 25 dB suppression, improving range and Doppler estimation of the fast mover.