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A MODULATION BASED APPROACH TO WIDEBAND-STAP (BRIEFING CHARTS)

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C & P Technologies, Inc.

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14. ABSTRACT

In this presentation, a new method for processing wideband radar data is presented. To perform the full degree of freedom wideband processing, 3-D space-time adaptive processing (STAP) needs to be implemented, which involves intense computational burden. One approach in this case is to do subband STAP processing and combine these outputs. In this presentation, instead of traditional subband processing, the incoming wide band data signal is modulated by multiple carriers, combined, and filtered prior to processing using narrowband STAP. This method offers a significant decrease in computation burden compared to the subband method.

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A Modulation Based Approach to Wideband-STAP

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Outline

- Wideband Array Data Modeling
- Optimum Wideband Processor
- Subband Processing
- New Approach: Subband Combining without Partitioning
- Conclusions

Time-Domain Wideband Clutter Generation

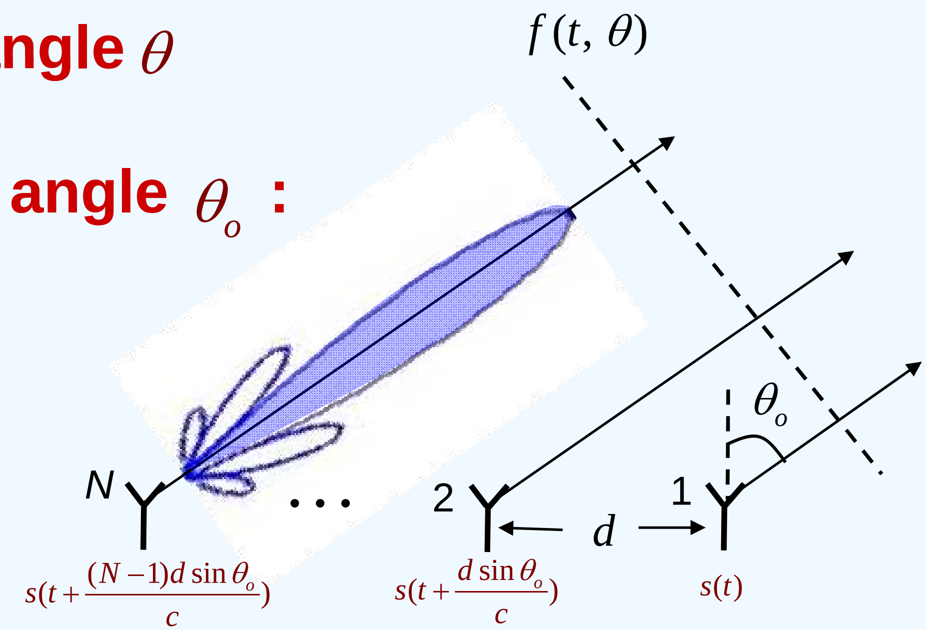
- Wideband signal $s(t)$ is transmitted from all sensors
- Delay taps are used at sensors to focus the transmitted signal to a specific look angle θ_o

$f(t, \theta)$: combined signal at angle θ

Combined signal at desired angle θ_o :

$$f(t, \theta_o) = N\, s(t)$$

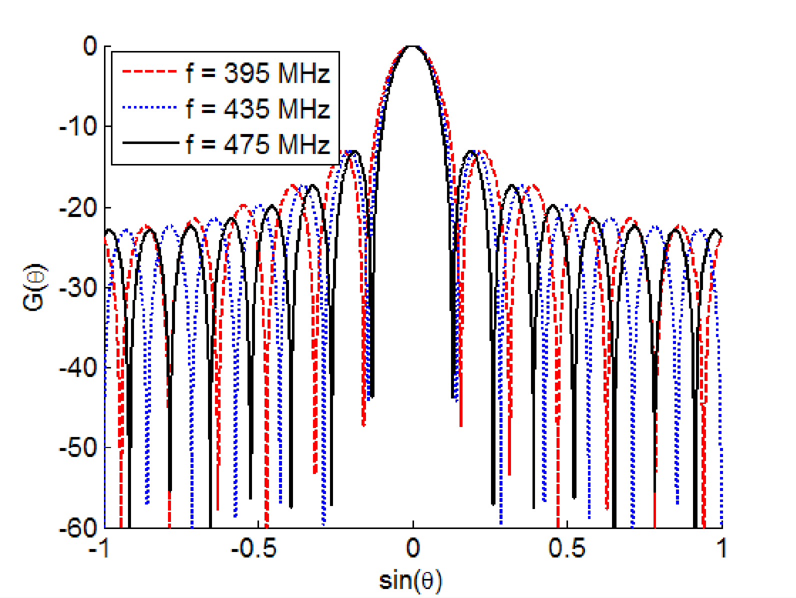
The combined signal at the desired look angle has been coherently amplified by a factor of N.



Time-Domain Wideband Clutter Generation

- For any other angle, the signals from different sensors will add up incoherently resulting in a transmit array gain pattern
- Combined signal at an arbitrary angle is given by:

$$f(t,\theta)=\sum_{n=1}^{N} s\left(t-(n-1)\frac{d\left(\sin\theta-\sin\theta_o\right)}{c}\right).$$



- Bandwidth $BW = 80\,MHz$
- Center frequency $f_c = 435\,MHz$
- Number of sensors $N = 14$
- Interelement spacing $d = 0.33\,m$
- Look angle $\theta_o = 0^o$
- PRF = 625 Hz

Mountain Top Radar Parameters are used

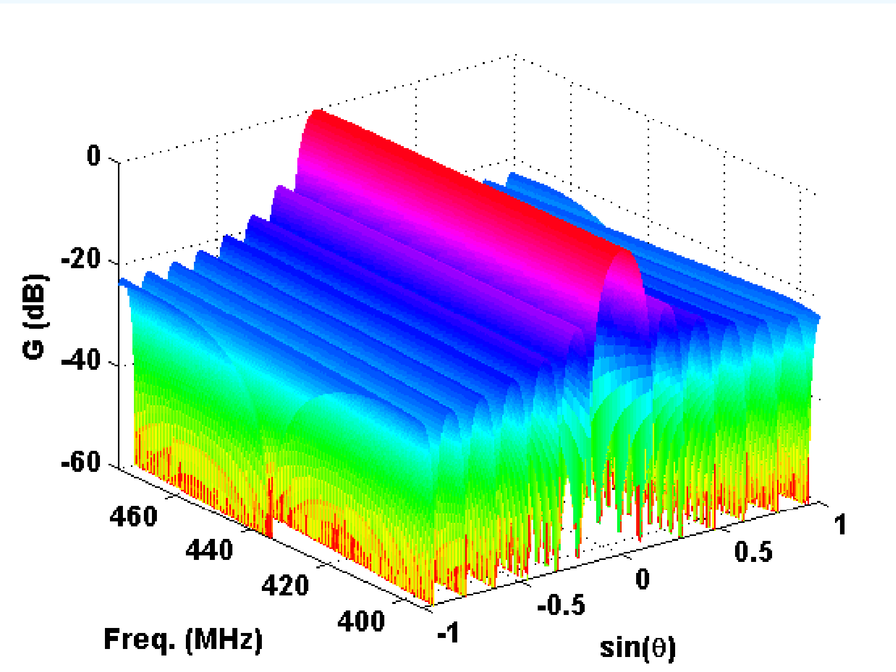
Frequency Sensitive Array Gain Pattern

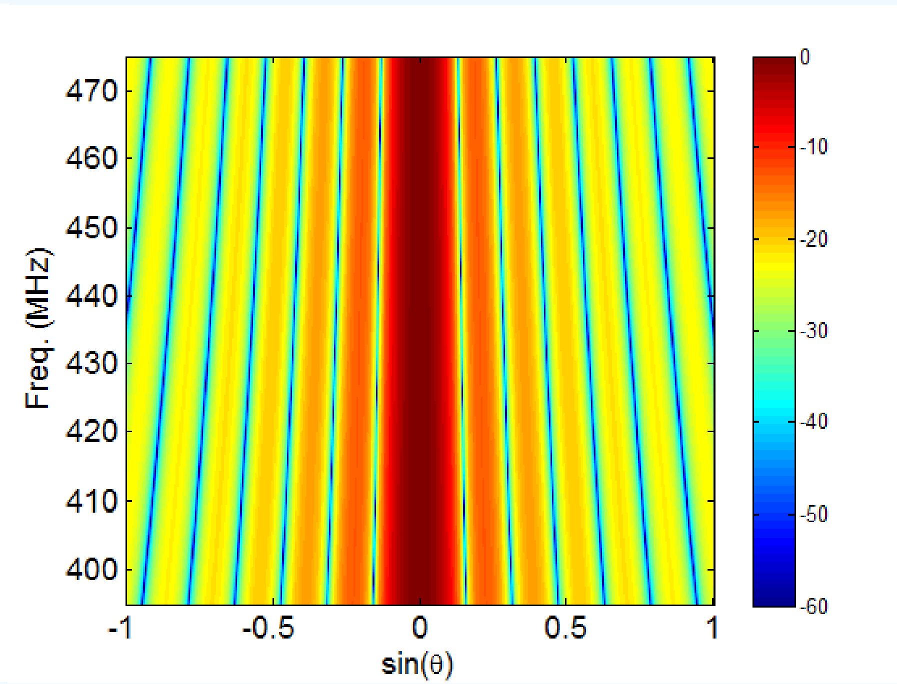
Array Amplitude Pattern

$$C(\theta,\,\omega_k) = \sum_{i=1}^{N} e^{-j2\pi\frac{d}{\lambda_k}(i-1)\sin\theta},$$

Array Gain Pattern

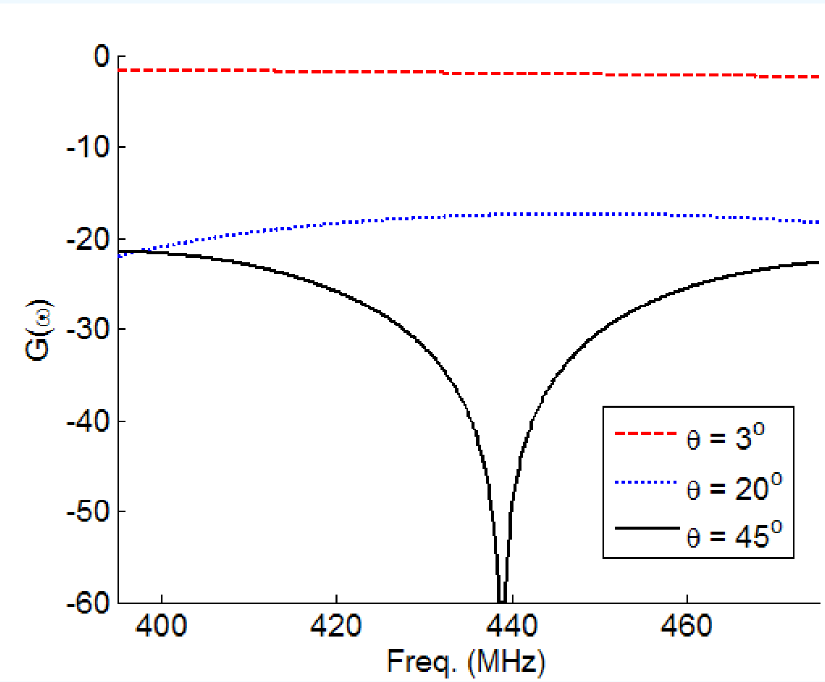
$$G(\theta,\,\omega_k) = \left|C(\theta,\,\omega_k)\right|^2$$



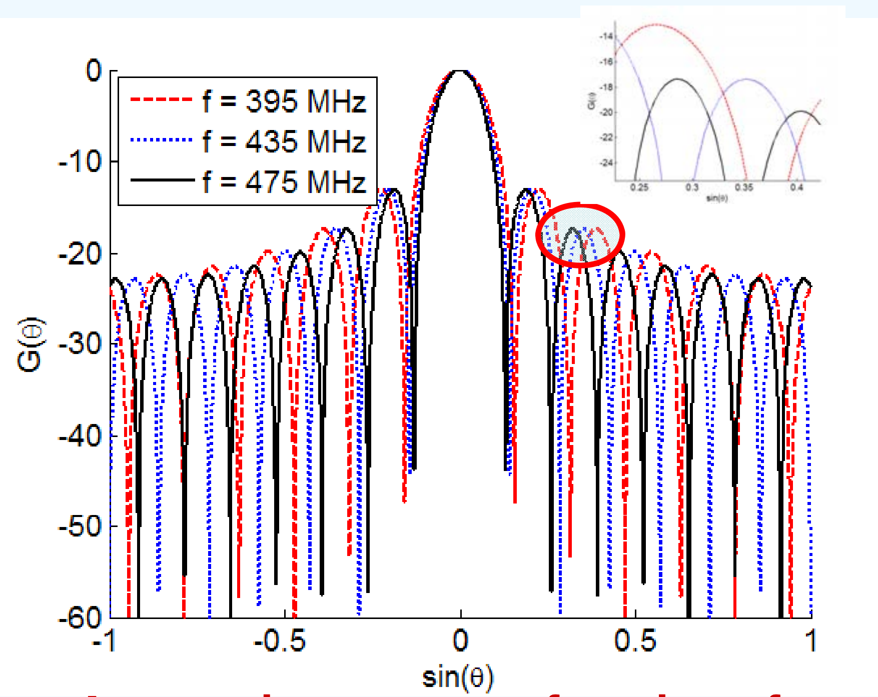


Bandwidth = 395 MHz - 475 MHz (80 MHz), Sensors used: 14

Array Gain Pattern (Freq. Domain)



Array gain pattern as function of frequency for different angles



Array gain pattern as function of angle for different frequencies

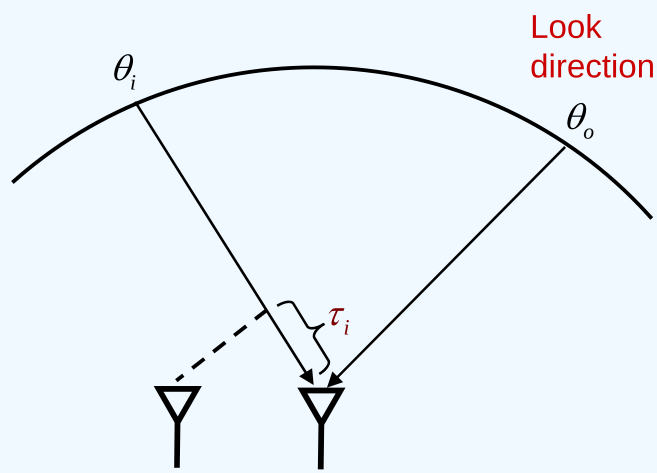
Time-Domain Wideband Clutter Generation

- The received signal vector arriving from θ_i for all the sensors is given by:

$$\underline{r}(t, \theta_i) = \alpha_i \begin{bmatrix} f(t, \theta_i) \\ f(t-\tau_i, \theta_i) \\ \vdots \\ f(t-(N-1)\tau_i, \theta_i) \end{bmatrix}$$

Clutter scatter return

$$\tau_i = \frac{d \sin \theta_i}{c}$$



- Wideband data vector received from all the azimuth angles is:

$$\underline{x}(t) = \sum_i \underline{r}(t, \theta_i)$$

Wideband STAP

N sensors, *M* pulses, Target in Clutter and Noise

$$\underline{x}(t) = \underline{f}(t) + \underline{c}(t)$$

M^{th} pulse output

$$\underline{x}(t) = \left[\underline{x}_1(t),\ \underline{x}_2(t),\ \cdots,\ \underline{x}_M(t)\right]^T$$

N^{th} sensor output

$$\underline{x}_i(t) = \left[x_{i,1}(t),\ x_{i,2}(t),\ \cdots,\ x_{i,N}(t)\right]$$

Target at θ_o, moving with velocity V (both parameters are unknown)

$$f_{ik}(t) = f\left(t - (i-1)\tau_1 - (k-1)\tau_2\right)$$

Sensor **Pulse**

Spatial: (Azimuth) $\tau_1 = \dfrac{d \sin\theta_o}{c}$, **Temporal: (Doppler)** $\tau_2 = \dfrac{2V\,T_r \sin\theta_o}{c} = \beta\,\tau_1$

Optimum Wideband Processor

Interference Covariance Matrix: $\mathbf{R}_c = E\left\{\underline{x}(t)\underline{x}^*(t)\right\}$

Optimum Processor:

(1) Whitening followed by (2) Matched Filter

(1) Whitening Filter $\mathbf{H}(z)$

White noise

$$\underline{x}(t) \Rightarrow \boxed{\mathbf{R}_c^{-1/2}} \Rightarrow \underline{y}(t) = \mathbf{R}_c^{-1/2}\underline{f}(t) + \underline{w}(t)$$

$$\Big[\underbrace{\big[f(t),\ \cdots,\ f(t-(N-1)\tau_1)\big]}_{\text{First pulse return}}\ \underbrace{\big[f(t-\tau_2),\ \cdots,\ f(t-\tau_2-(N-1)\tau_1)\big]}_{\text{Second pulse return}}\ \underbrace{\big[\cdots,\ \cdots,\ \cdots\big]}_{m^{th}\text{ pulse return}}\Big]^T$$

Optimum Wideband Processor – Freq. Domain

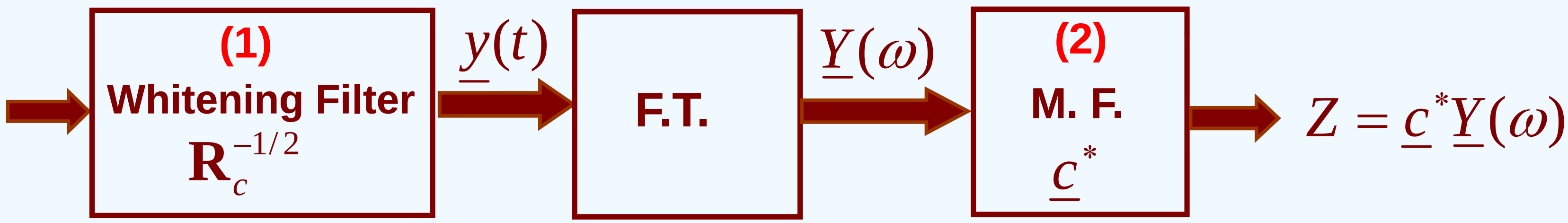
$$\underline{Y}(\omega) = F(\omega)\mathbf{R}_c^{-1/2} \underbrace{\begin{bmatrix} \begin{bmatrix} 1 \\ e^{-j\omega\tau_1} \\ \vdots \\ e^{-j\omega(N-1)\tau_1} \end{bmatrix} = \underline{a}(\theta,\omega) \\ e^{-j\omega\tau_2}\underline{a}(\theta,\omega) \\ \vdots \\ e^{-j\omega(M-1)\tau_2}\underline{a}(\theta,\omega) \end{bmatrix}}_{\underline{b}(V,\,\omega)\otimes\underline{a}(\theta,\,\omega)\,=\,\underline{s}(\theta,\,V,\,\omega)} + \underline{w}(\omega)$$

Frequency Sensitive
STAP Steering Vector

$$= F(\omega)\mathbf{R}_c^{-1/2}\underline{s}(\theta, V, \omega) + \underline{w}(\omega) = \underline{c} + \underline{v}$$

(2) Matched Filter is given by $\underline{c}^*$

Optimum Wideband Processor



$$
\begin{aligned}
Z &= \underline{c}^* \underline{Y}(\omega) \\
&= \left(\underline{s}^*(\theta, V, \omega) \mathbf{R}_c^{-1/2} \right) \left(\mathbf{R}_c^{-1/2} \, \underline{X}(\omega) \right) \\
&= \underline{s}^*(\theta, V, \omega) \, \mathbf{R}_c^{-1} \, \underline{X}(\omega) = \underline{W}^*(\omega) \; \underline{X}(\omega)
\end{aligned}
$$

Optimum wideband STAP Processor:

$$\underline{W}(\omega) \;\; = \mathbf{R}_c^{-1} \underline{s}(\theta, V, \omega)$$

Frequency sensitive processor. Same form as in the narrowband case; Difficult to implement.

Wideband STAP Processor

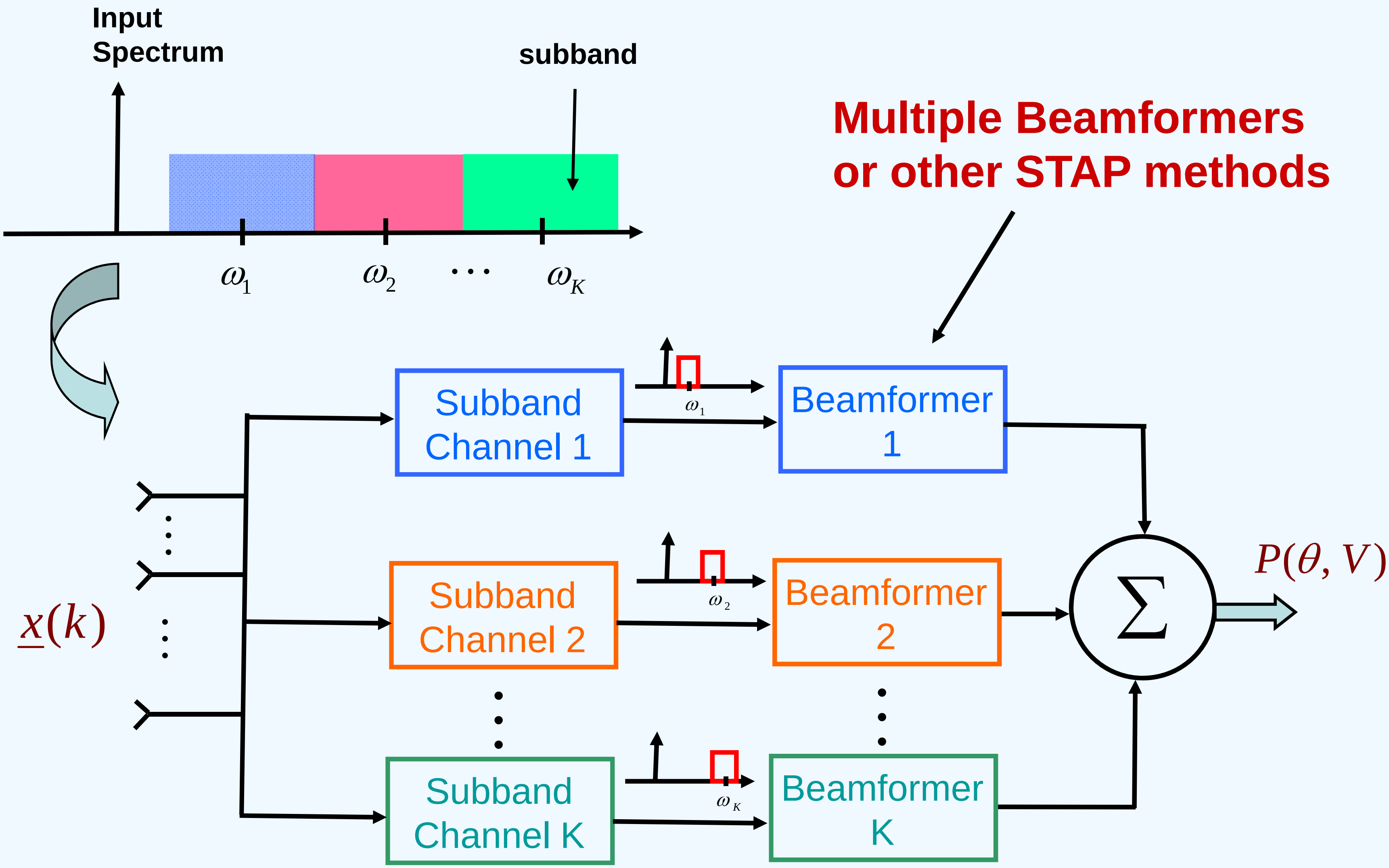
- **Phase delays become frequency sensitive filters**
- **STAP Processor must be compensated at *all* frequencies – difficult to implement**

In practice, use subband schemes

Subband schemes are suboptimal since narrowband processing is done on each subband

Objective: Avoid subband processing

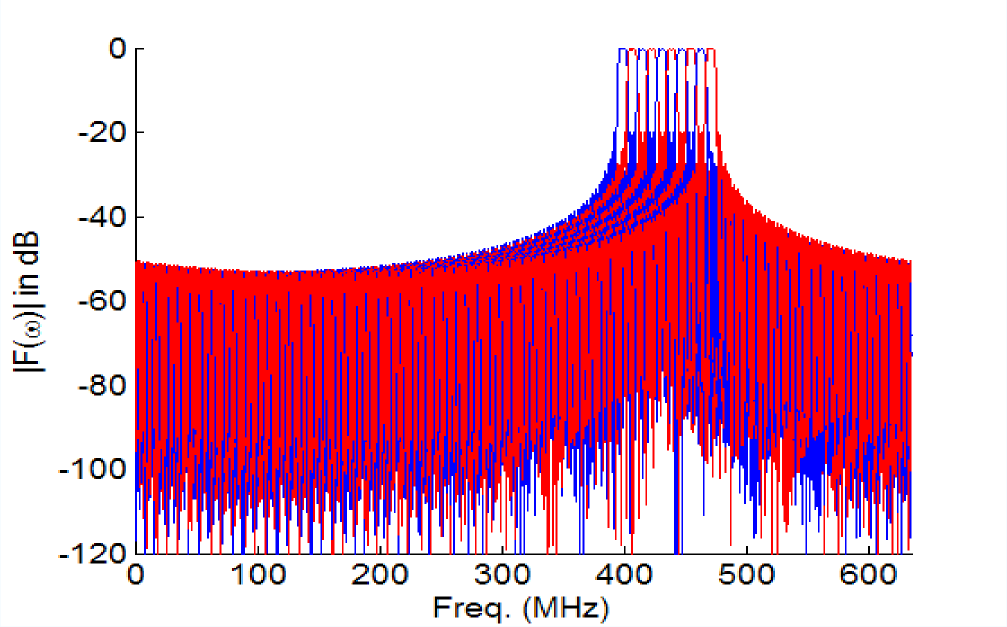
Multiple Subband STAP



Subband Filter Design

Subband filter design using modulated linear phase low pass FIR filters

$$h_{BP}(n) = h_{LP}(n)e^{j2\pi f_i n T_s} \leftrightarrow H_{BP}(e^{j\omega}) = H_{LP}(e^{j(\omega - 2\pi f_i)})$$

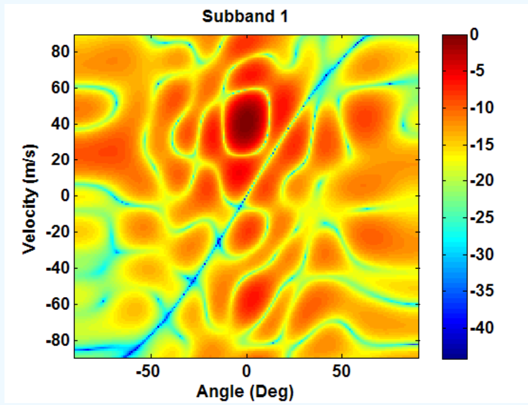


- Signal BW = 80MHz
- 8 MHz (3dB BW)
- 10 Sub-Bands

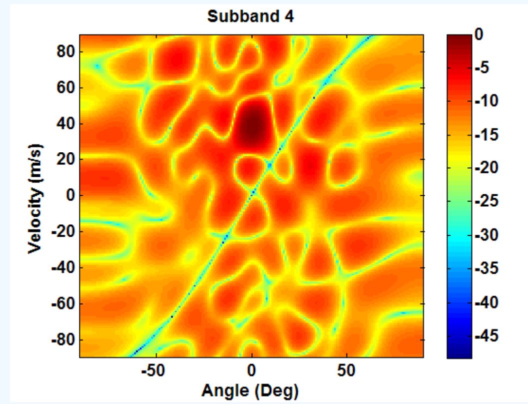
Mountain Top radar carrier freq. = 435 MHz. Wideband data BW = 80 MHz

Typical Subband STAP Outputs (SMIDL)

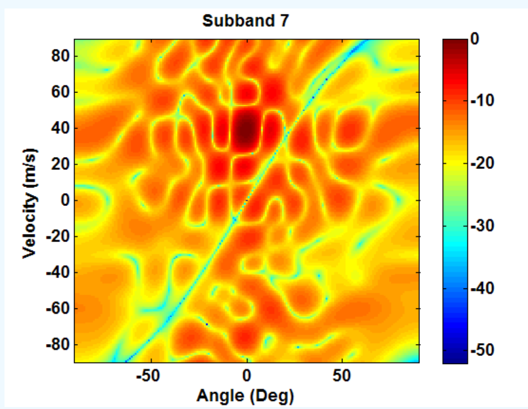
SMIDL with subarray smoothing using 20 Samples



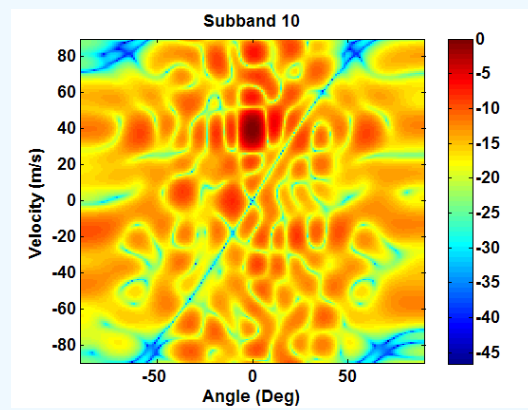
(a) Subband 1, Freq. = 395 MHz



(b) Subband 4, Freq. = 419 MHz



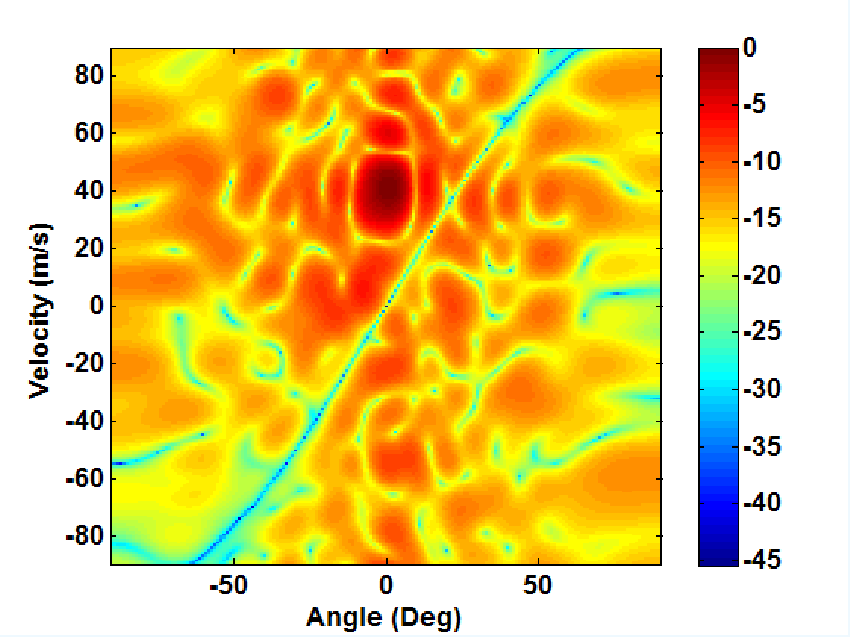
(c) Subband 7, Freq. = 443 MHz



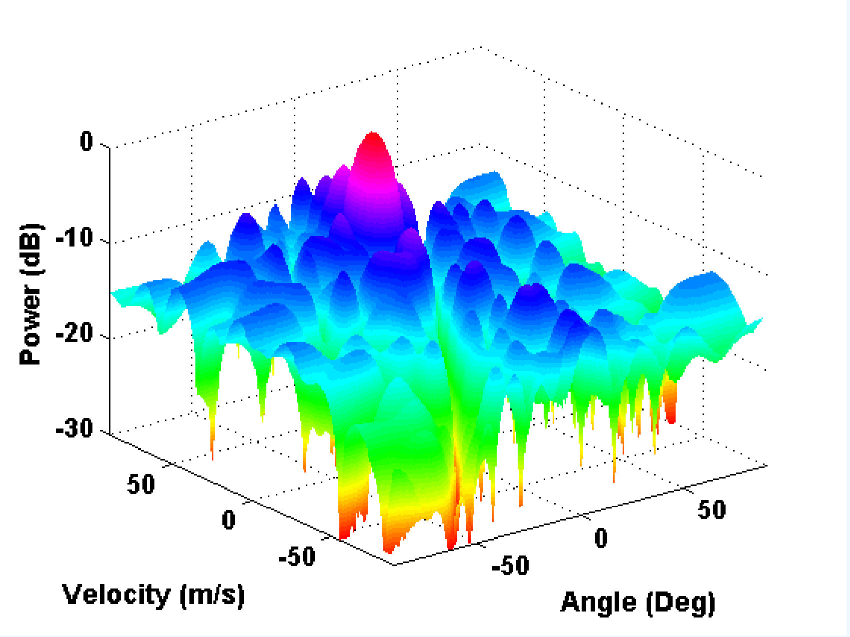
(d) Subband 10, Freq. = 467 MHz

CNR = 40dB, SNR = 0dB, Target at 0° moving at 40m/s

Subband Averaging (10 Subbands)



(a) Top View



(b) Side View

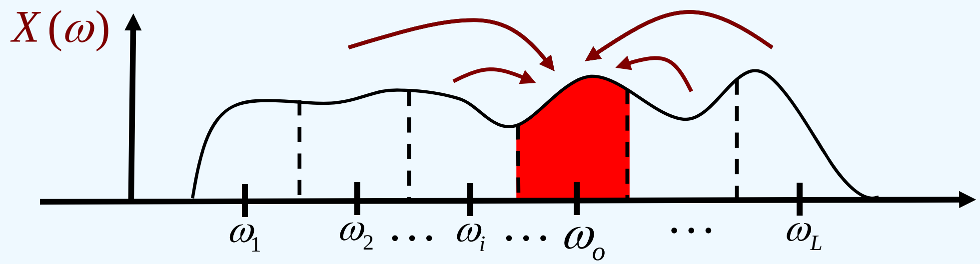
Substantial computational burden for subband methods

New Approach
Subband Combining Without Subband Partitioning

Objectives:

- **Use the entire wideband information**
- **Avoid/minimize subbanding**
- **Take advantage of narrowband STAP**

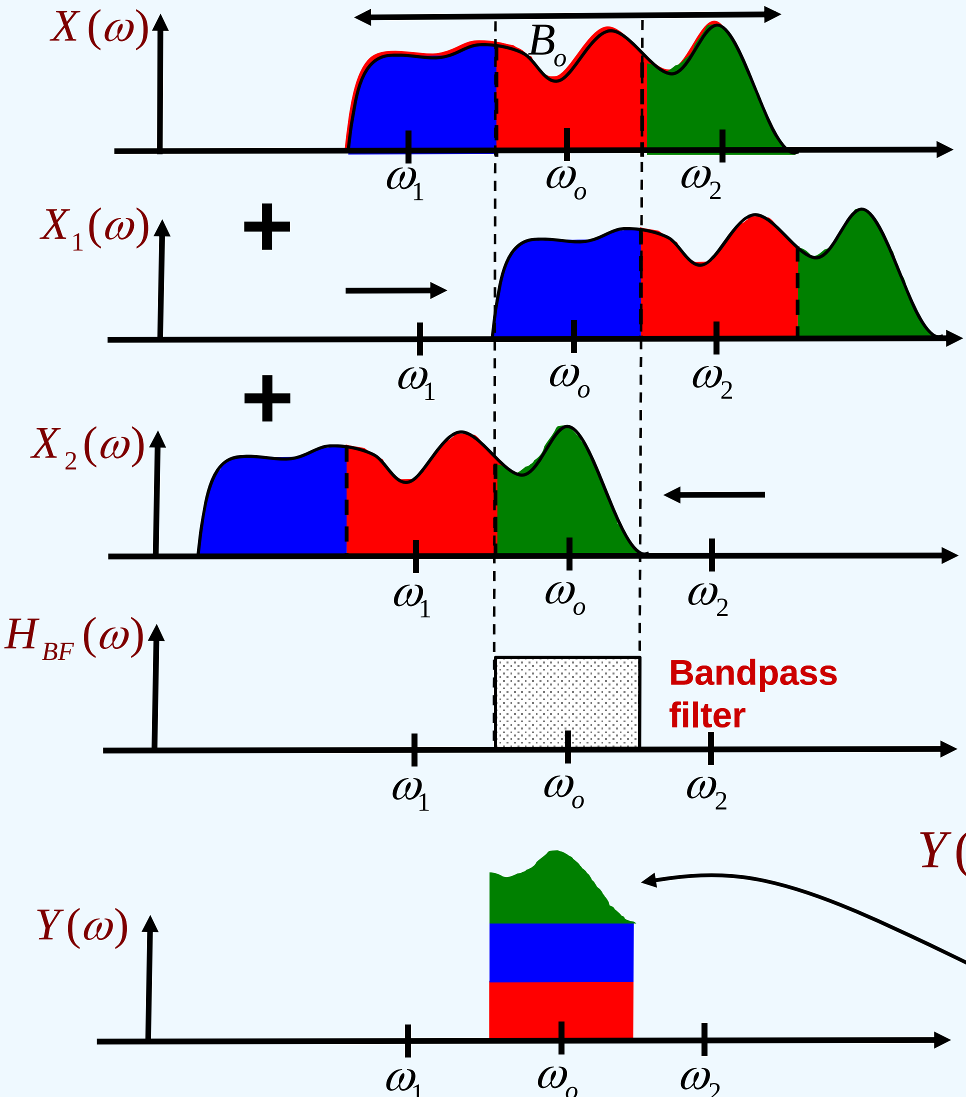
Wideband Processing:
Subband Combining Without Subband Partitioning



- Imagine the wideband signal partitioned into L subbands (No physical partitioning)
- Select one band centered at ω_o for actual processing
- Modulate the signal by various carrier frequencies and align the subbands with the selected band
- Perform a single subband filtering at the final stage
- Apply narrowband STAP and align the outputs

Modulate, Combine, Filter and Align

Subband Combining Without Subband Partitioning
Example



- Entire bandwidth is partitioned into subbands
- Data is modulated by different carrier freq. and then combined
- A single band pass filter is applied to the summed data

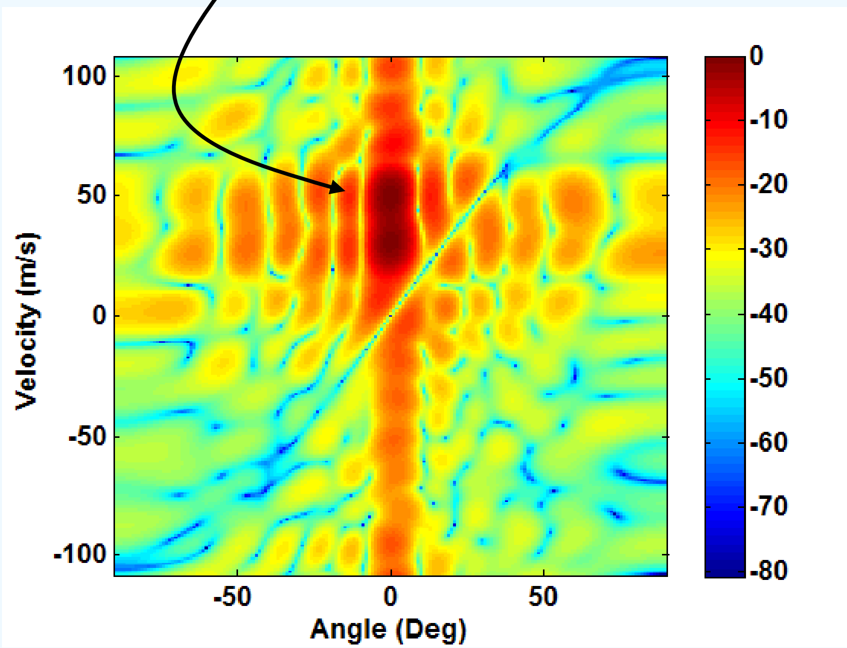
$$y(n) = x(n)\sum_{k=0}^{2} e^{j(\omega_o-\omega_k)n} * h_{BP}(n)$$

$$Y(\omega) = \left(X(\omega) + X_1(\omega) + X_2(\omega)\right) H_{BP}(\omega)$$

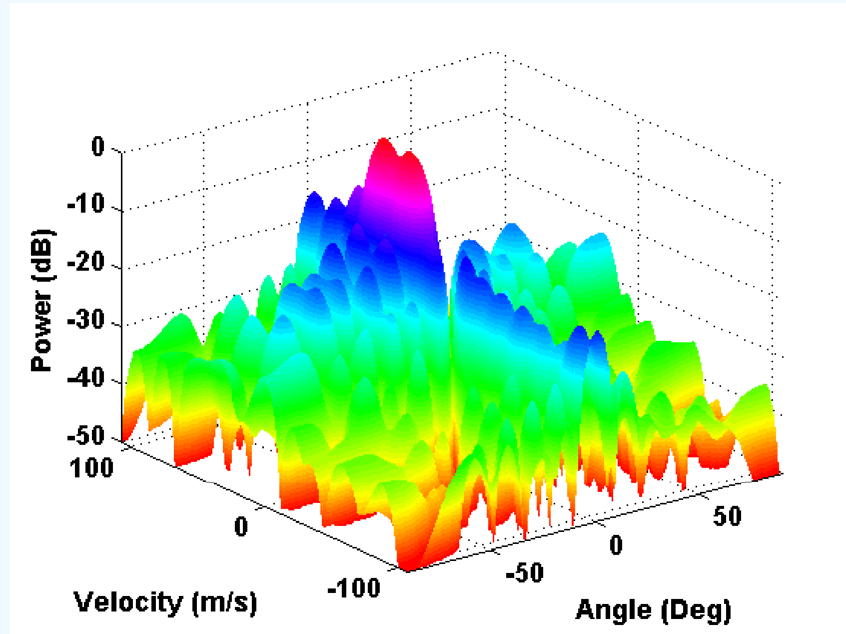
Narrowband STAP on $y(n)$

Modulate, Combine and Filter – 10 Modulations

Doppler spread



(a) Top View

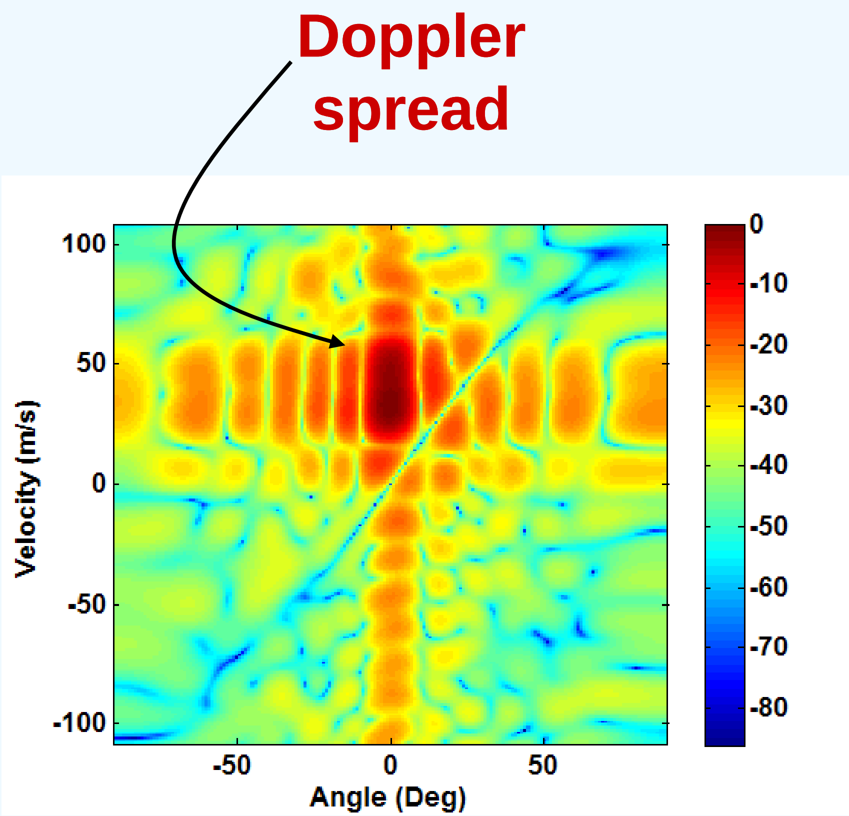


(b) Side View

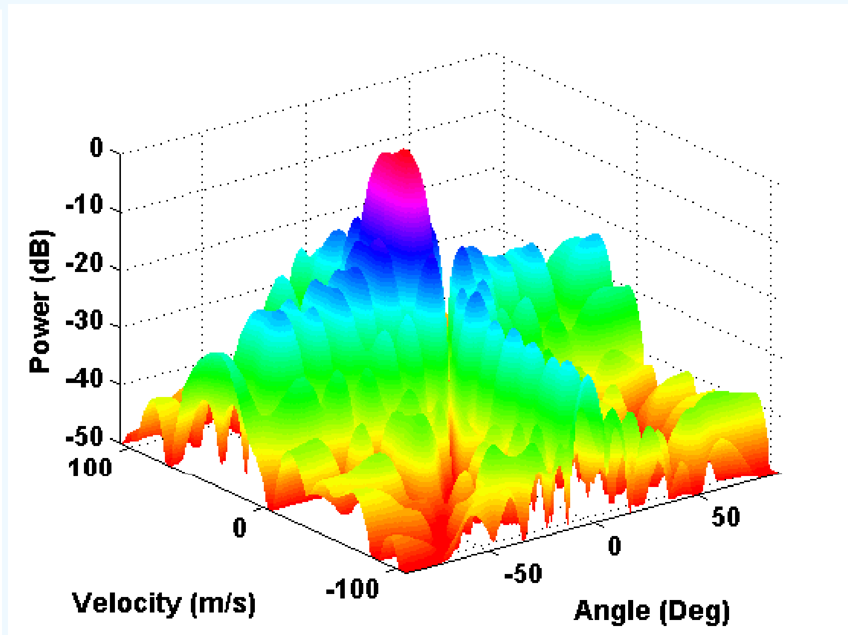
Data is modulated by 10 carrier frequencies to 435 MHz.

SMIDL using data at 435 MHz with 10 range samples.

Modulate, Combine and Filter – 20 Modulations



(a) Top View



(b) Side View

Data is modulated by 20 carrier frequencies to 435 MHz.

SMIDL using data at 435 MHz with 10 range samples.

Modulate, Combine, Filter and Align

- A single target at θ_1 in the filtered data generates multiple direction vectors corresponding to frequencies $\omega_1, \omega_2, \cdots, \omega_L$
- Or equivalently, processing at ω_o generates multiple targets at $\theta_1, \theta_2, \cdots, \theta_L$ where

$$\omega_o \sin\theta_1 = \omega_k \sin\theta_k, \quad k = 2, 3, \cdots, L$$

- "Angle-Doppler spread" in STAP output spectrum processed at a single frequency ω_o
- Align the angle-Doppler spectrum to compensate for the Doppler spread

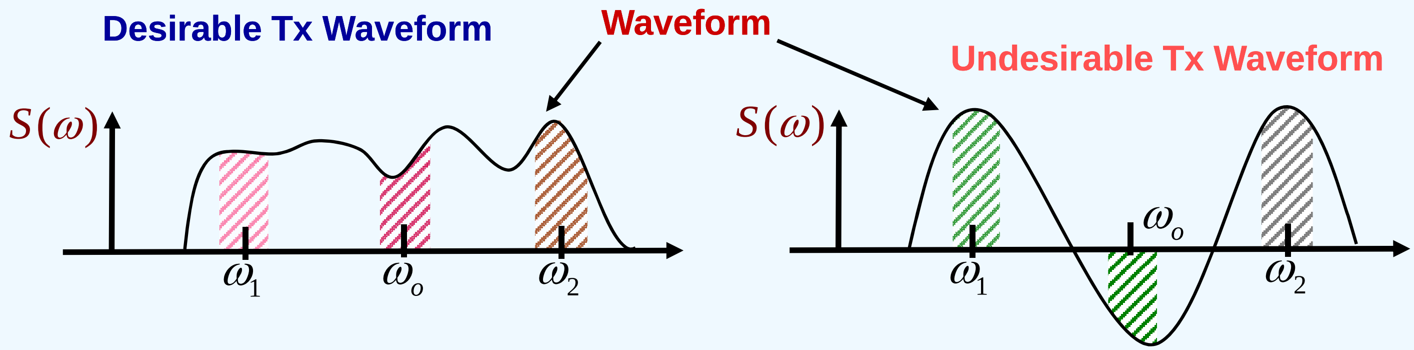
Waveform Design for Coherent Combining

- **Target return**

Spatio-temporal steering vector

$$\underline{S}_t(\omega) = S(\omega)\,\underline{a}(\omega,\, \theta_t,\, \omega_{d_t})$$

Transmit Waveform



- **Transmit waveform magnitude/phase variations should be minimized (Waveform Design)**
- **Present method avoids subband processing (one subband only) and uses the entire wideband information**
- **Takes advantage of narrowband STAP**

Conclusions

- Method presented here is ideal for initial search over a large region
- Present method avoids subband processing (one subband only) and uses the entire wideband information
- Doppler spreading needs to be compensated
- Use waveform diversity for coherent combining.