ASAP 2003 WORKSHOP
11 March 2003

REGISTRATION-BASED SOLUTIONS TO THE RANGE-DEPENDENCE PROBLEM IN STAP RADARS

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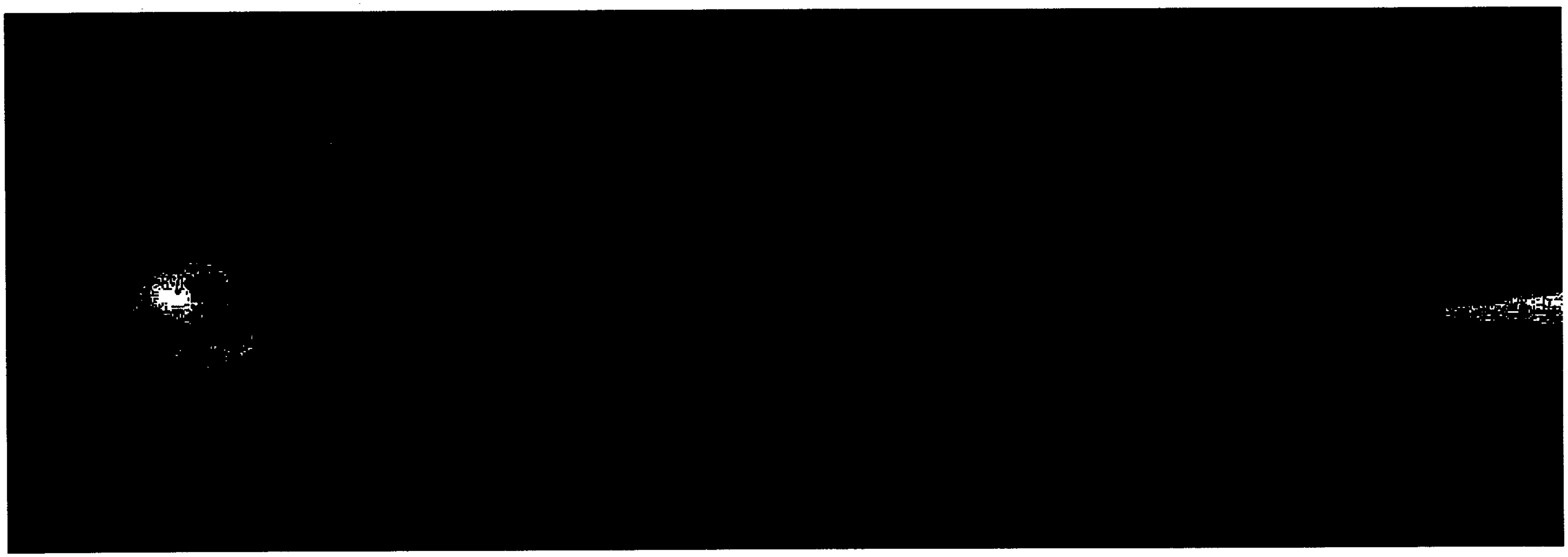
INTRODUCTION



- GOAL: TARGET DETECTION FOR ARBITRARY, POSSIBLY UNKNOWN BISTATIC CONFIGURATIONS
- DIFFICULTY: COMPLEX NATURE OF RANGE-DEPENDENT BISTATIC CLUTTER

OUTLINE

- INTRODUCTION
- CONFIGURATIONS AND SIGNALS
- RANGE-DEPENDENCE PROBLEM
- SNAPSHOT AND SPECTRUM
- STAP PROCESSOR
- EXISTING COMPENSATION METHODS
- NEW REGISTRATION-BASED METHODS
- SUMMARY

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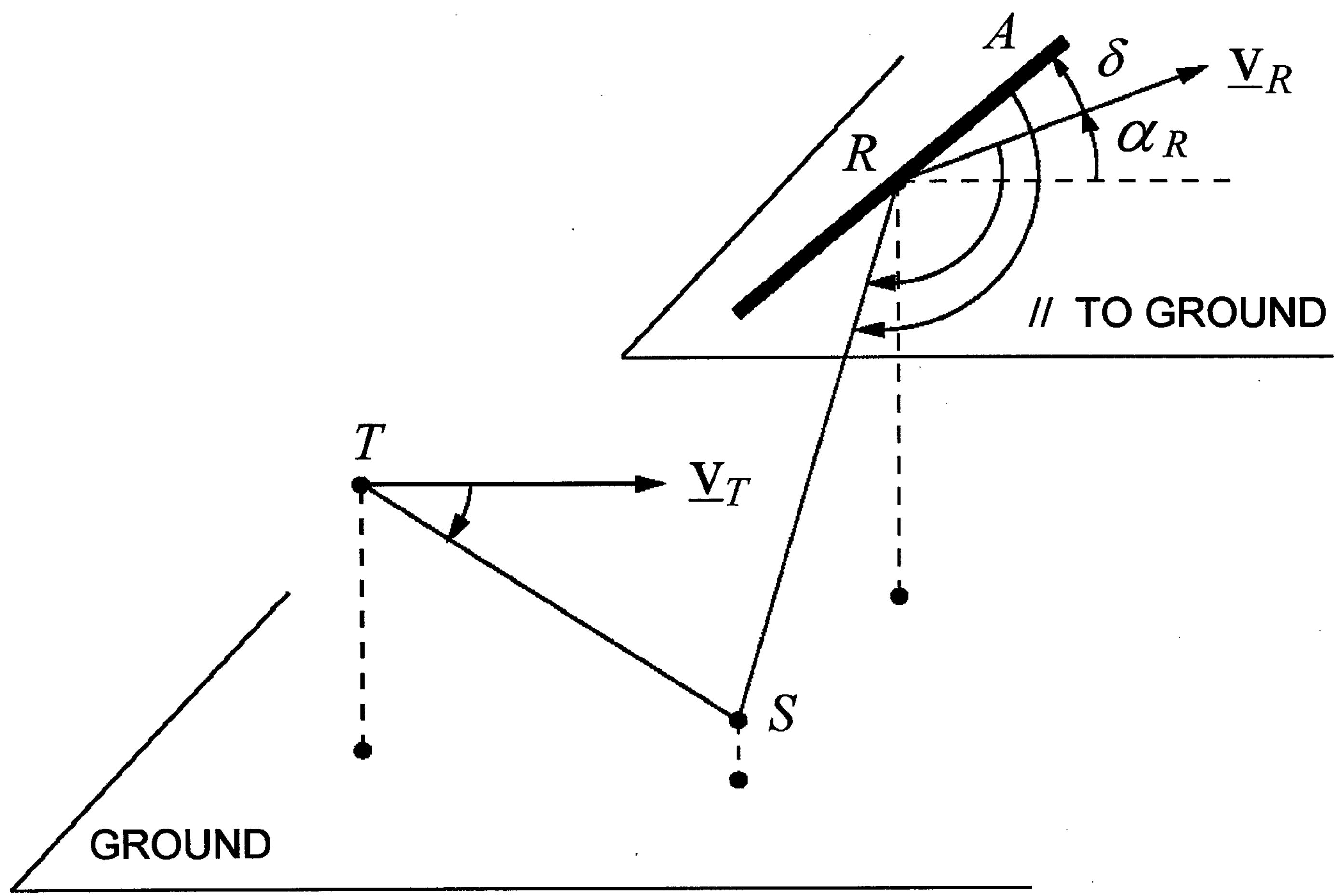
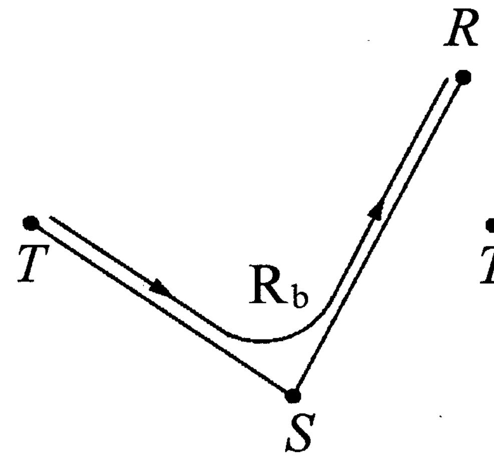
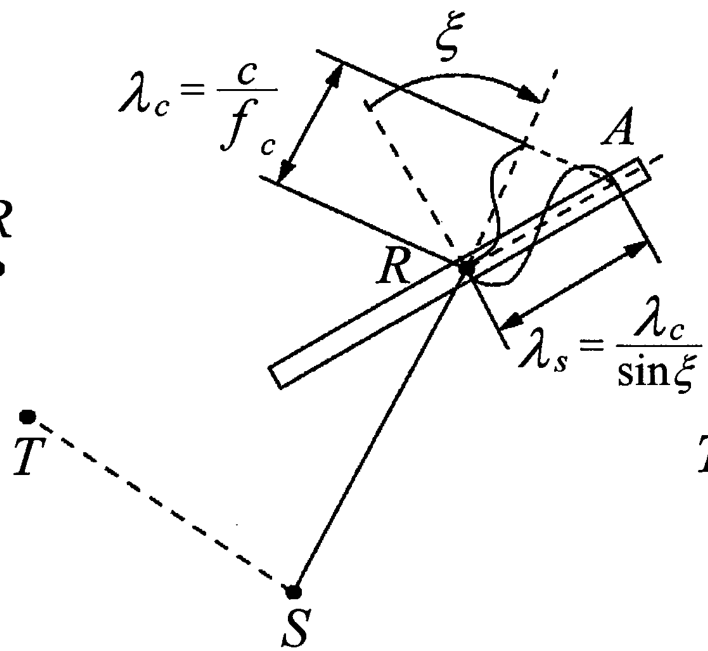
RADAR-MEASUREMENT CONFIGURATION: BISTATIC

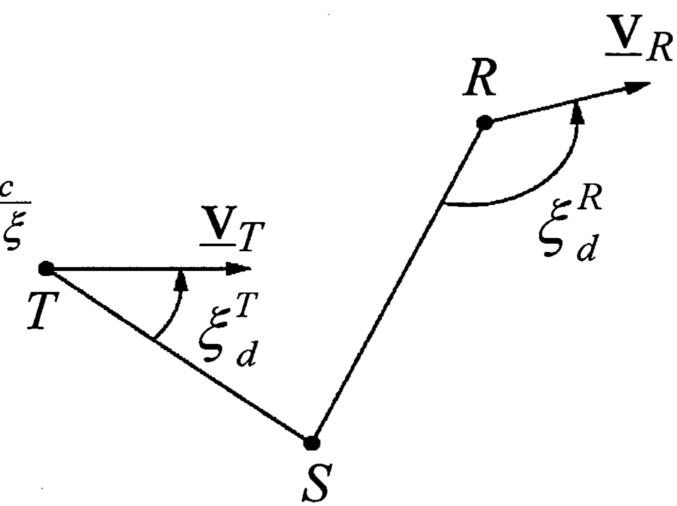


GROUND IS ASSUMED TO BE A FLAT (HORIZONTAL) PLANE

WHAT DOES THE RADAR MEASURE ?
DUAL VIEW







$$\tau_{rt} = \frac{R_b}{c}$$

$$f_s = \frac{1}{\lambda_s} = \frac{\sin\xi}{\lambda_c}$$

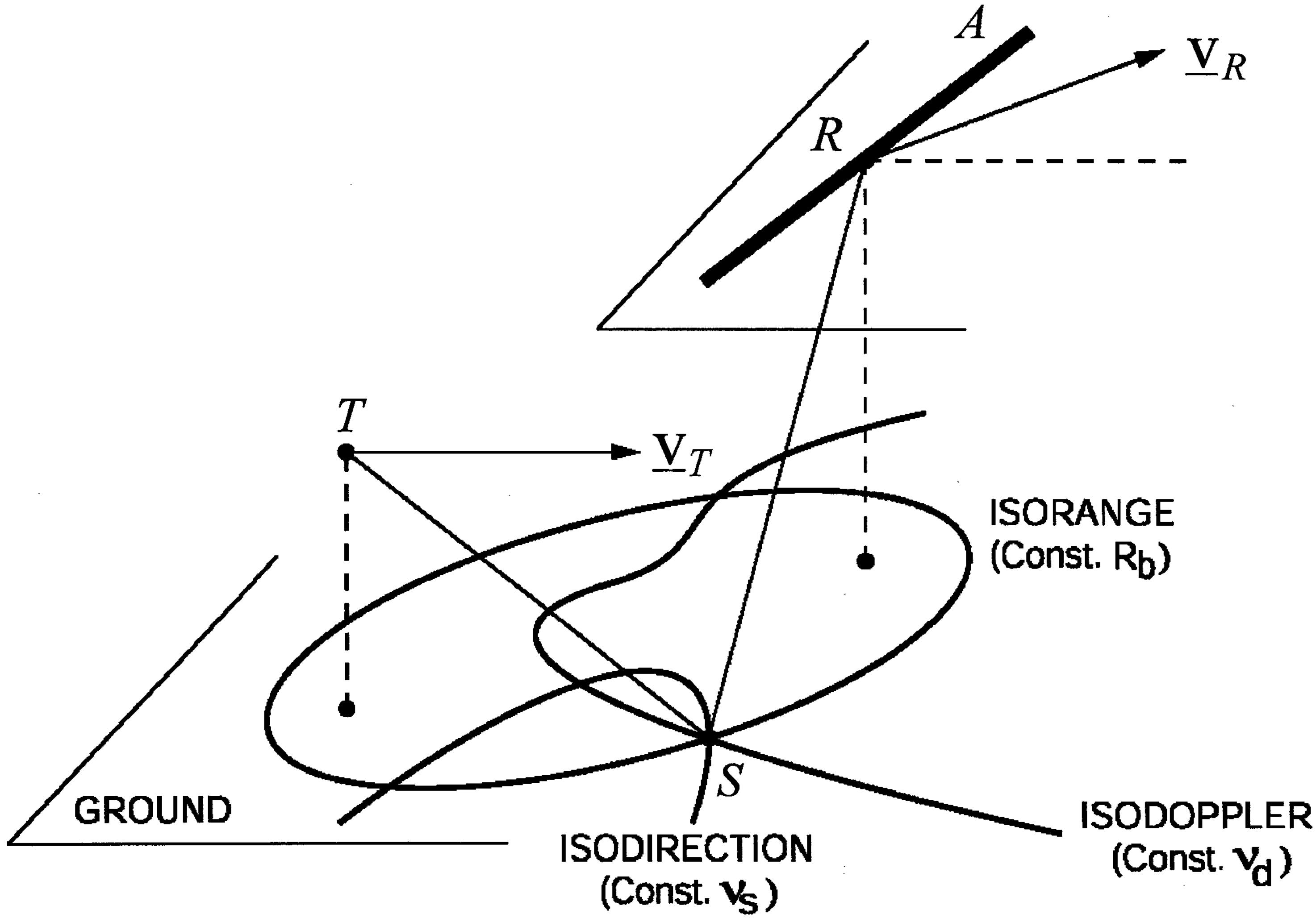
$$f_d = \frac{V_T}{\lambda_c}\cos\xi_d^T + \frac{V_R}{\lambda_c}\cos\xi_d^R$$

``ROUNDTRIP´´ DELAY τ_{rt}

SPATIAL FREQUENCY $f_s \rightarrow \nu_s$

DOPPLER FREQUENCY $f_d \rightarrow \nu_d$

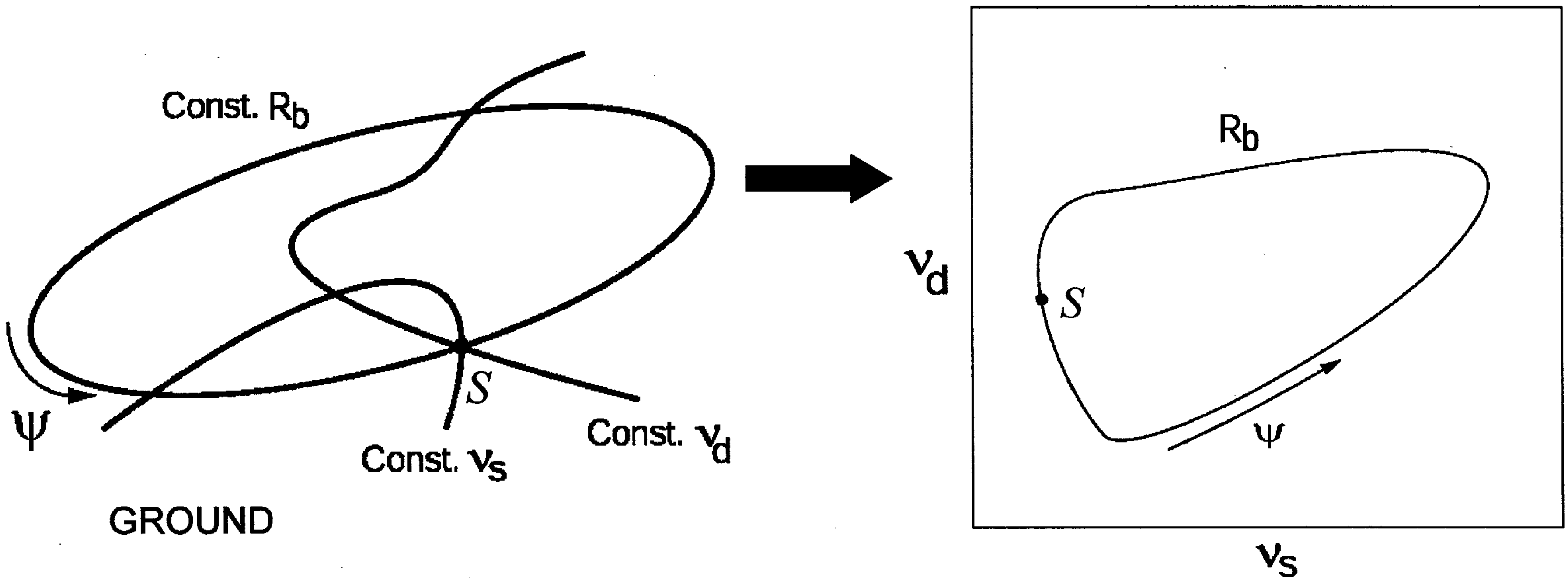
ALTERNATE POSITIONING SYSTEM: ISOSURFACES AND ISOCURVES



ABSTRACTING CONFIGURATIONS AND SIGNALS: DIRECTION-DOPPLER (DD) CURVES

ISOCURVES
(R_b, ν_s, ν_d)

DIRECTION-DOPPLER (DD) CURVES
(for a given R_b)



WHAT HAPPENS WHEN R_b CHANGES ?

University of Liège

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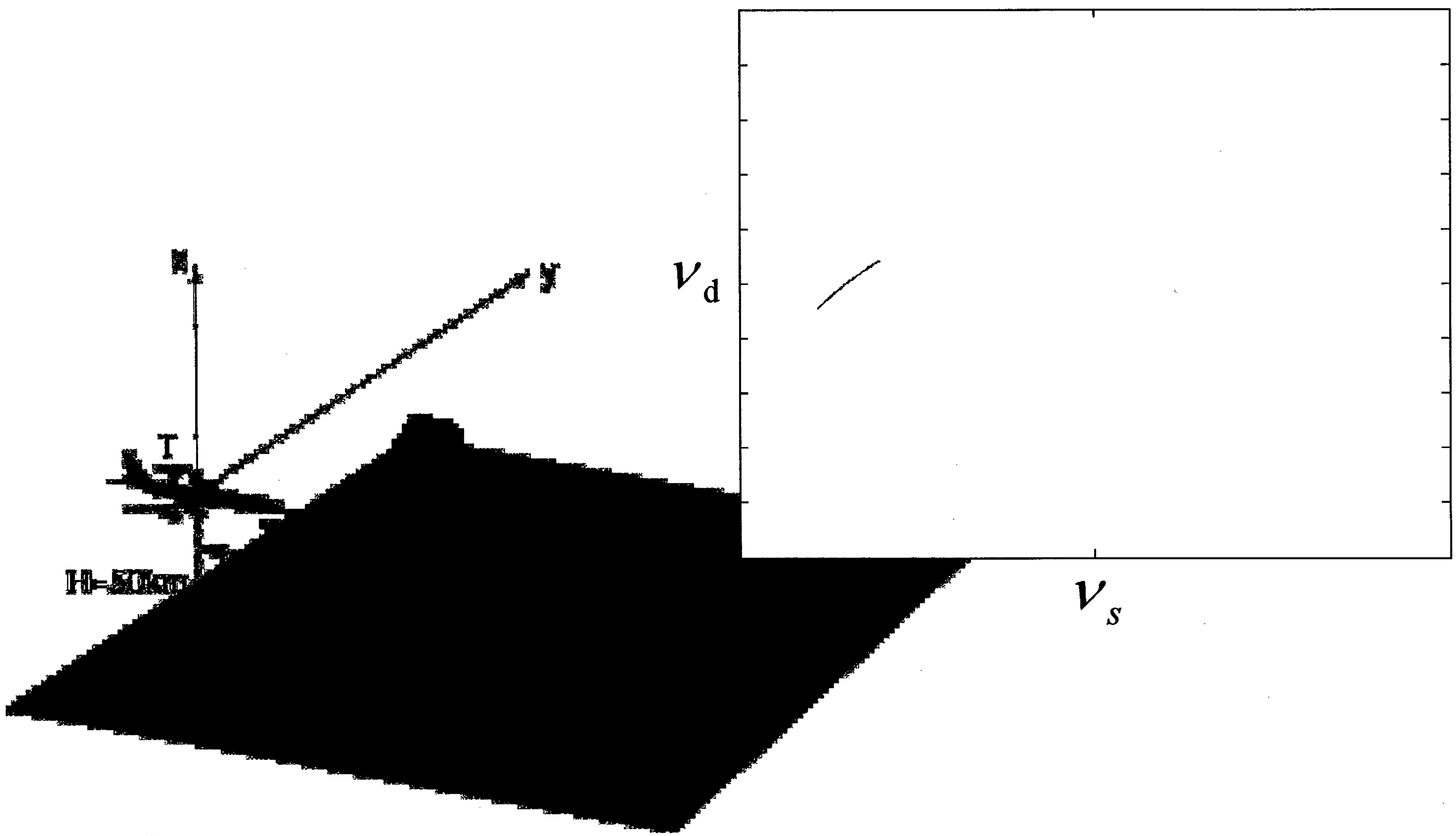
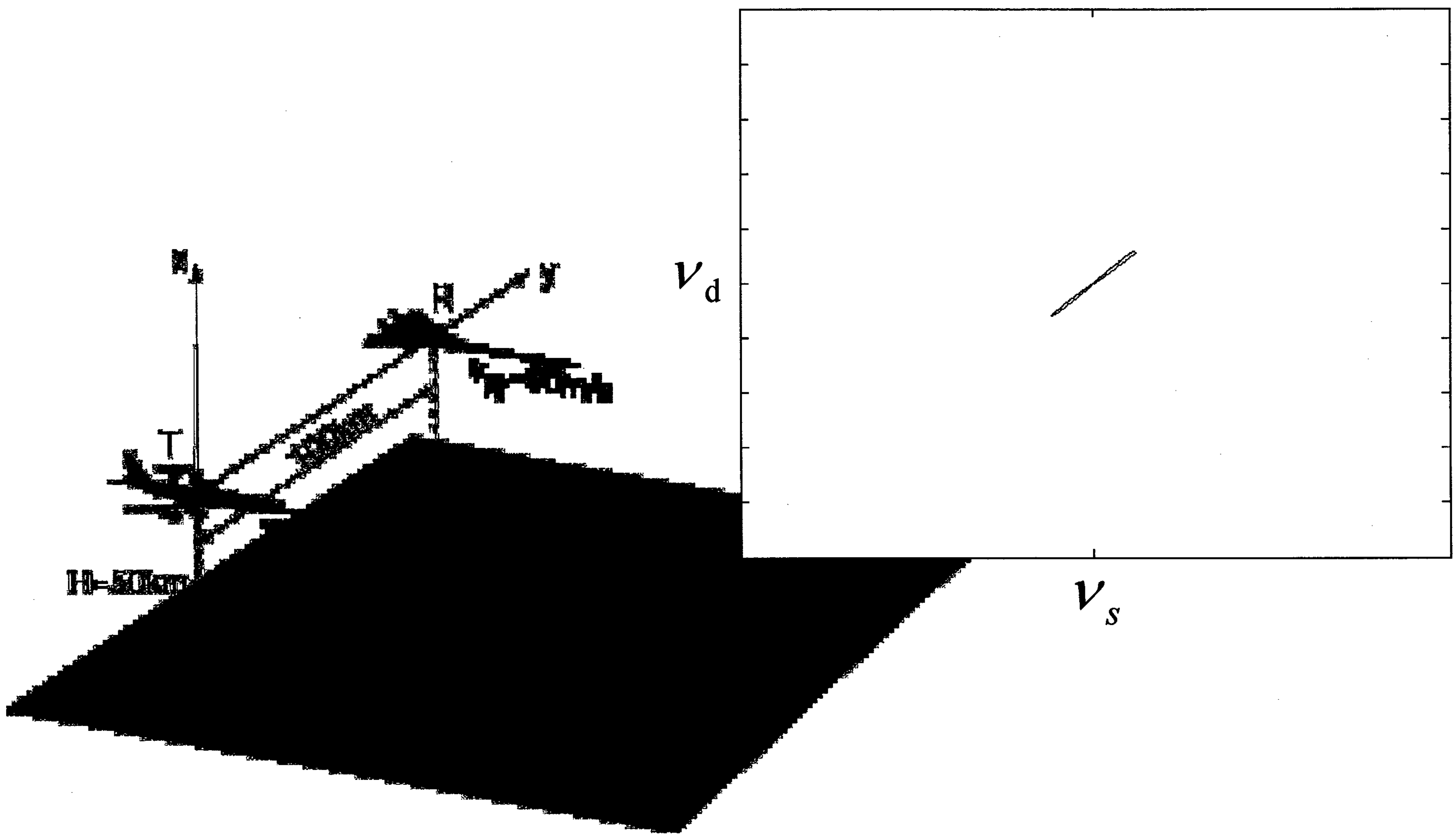
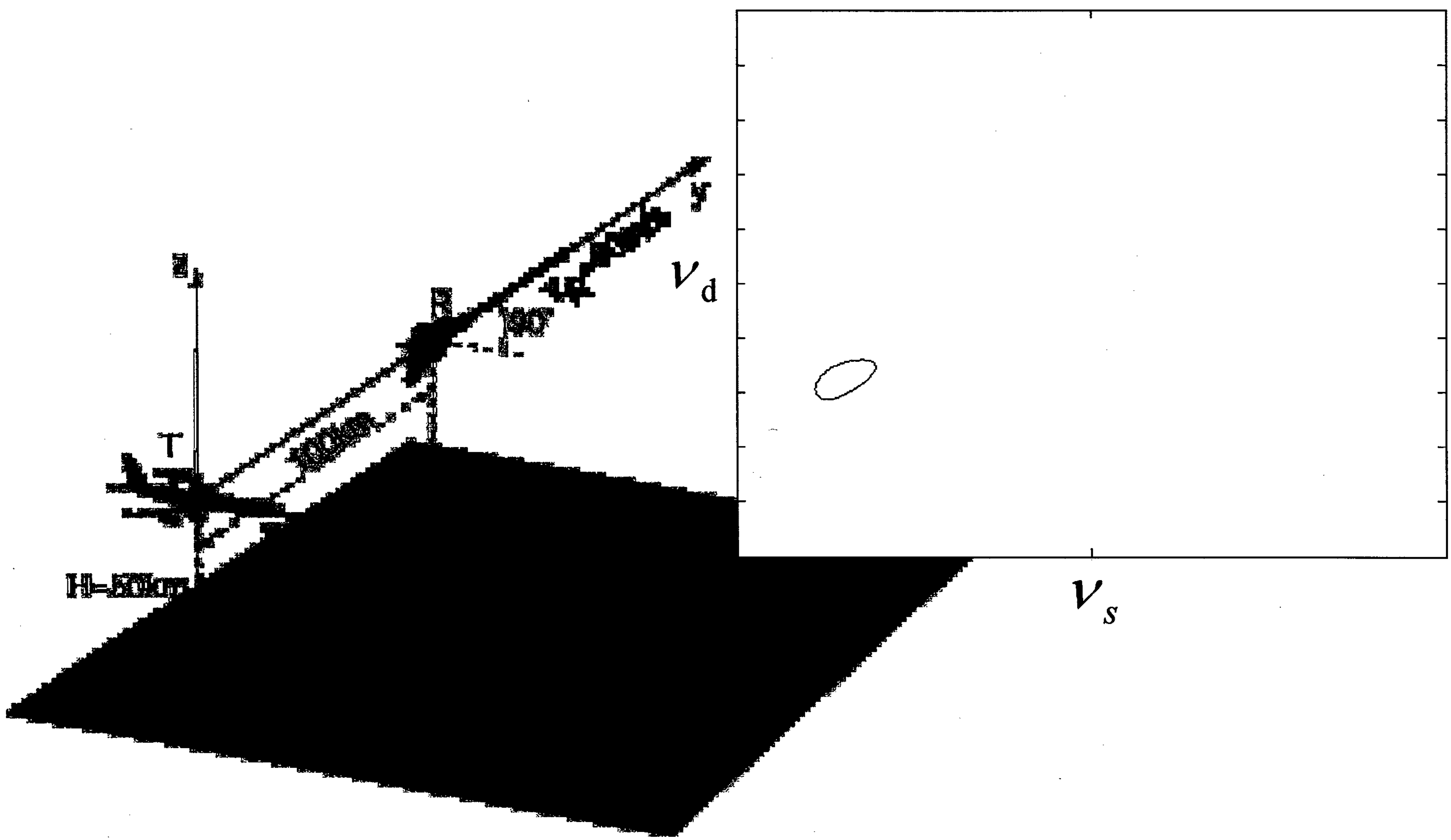
EXAMPLE DD CURVES: BISTATIC, IN-TRAIL, SIDELOOKING



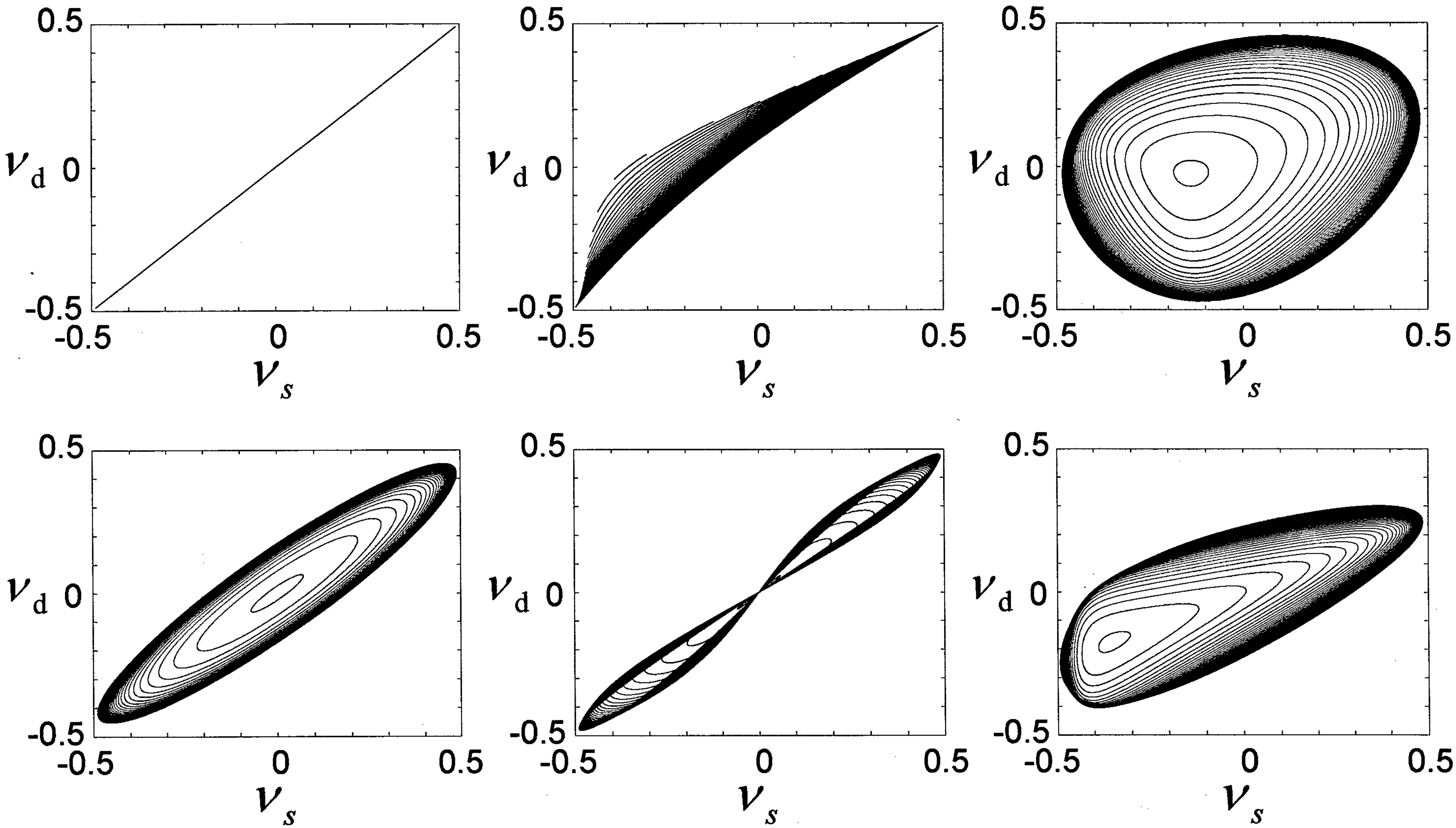
EXAMPLE DD CURVES:
BISTATIC, WING-TO-WING, SIDELOOKING



EXAMPLE DD CURVES: BISTATIC, WING-TO-FUSELAGE, SIDELOOKING



PROBLEM: DD CURVES ARE RANGE-DEPENDENT! (EXCEPT FOR MONOSTATIC-SIDELOOKING CASE)



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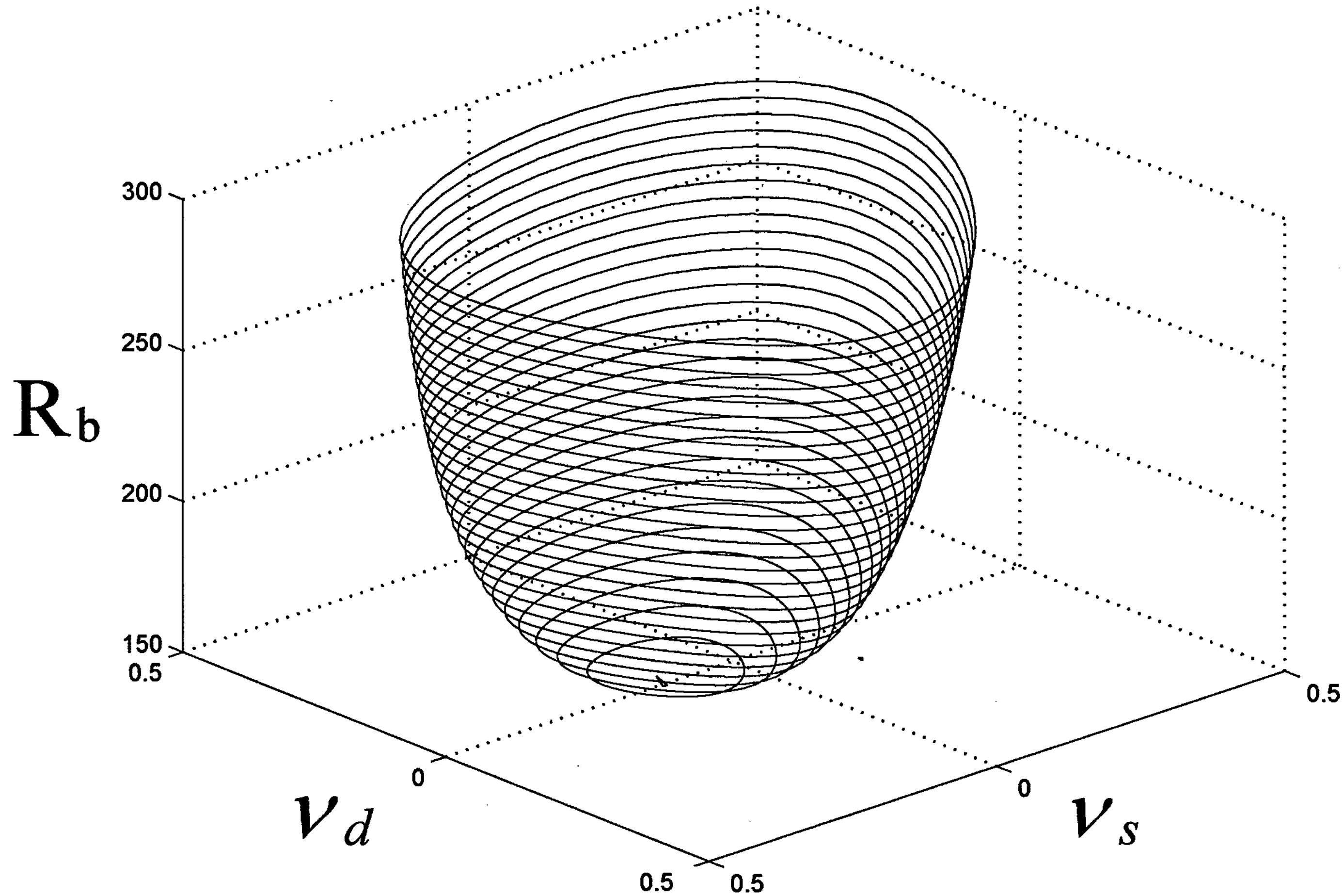
USEFUL CONCEPT: DD SURFACE



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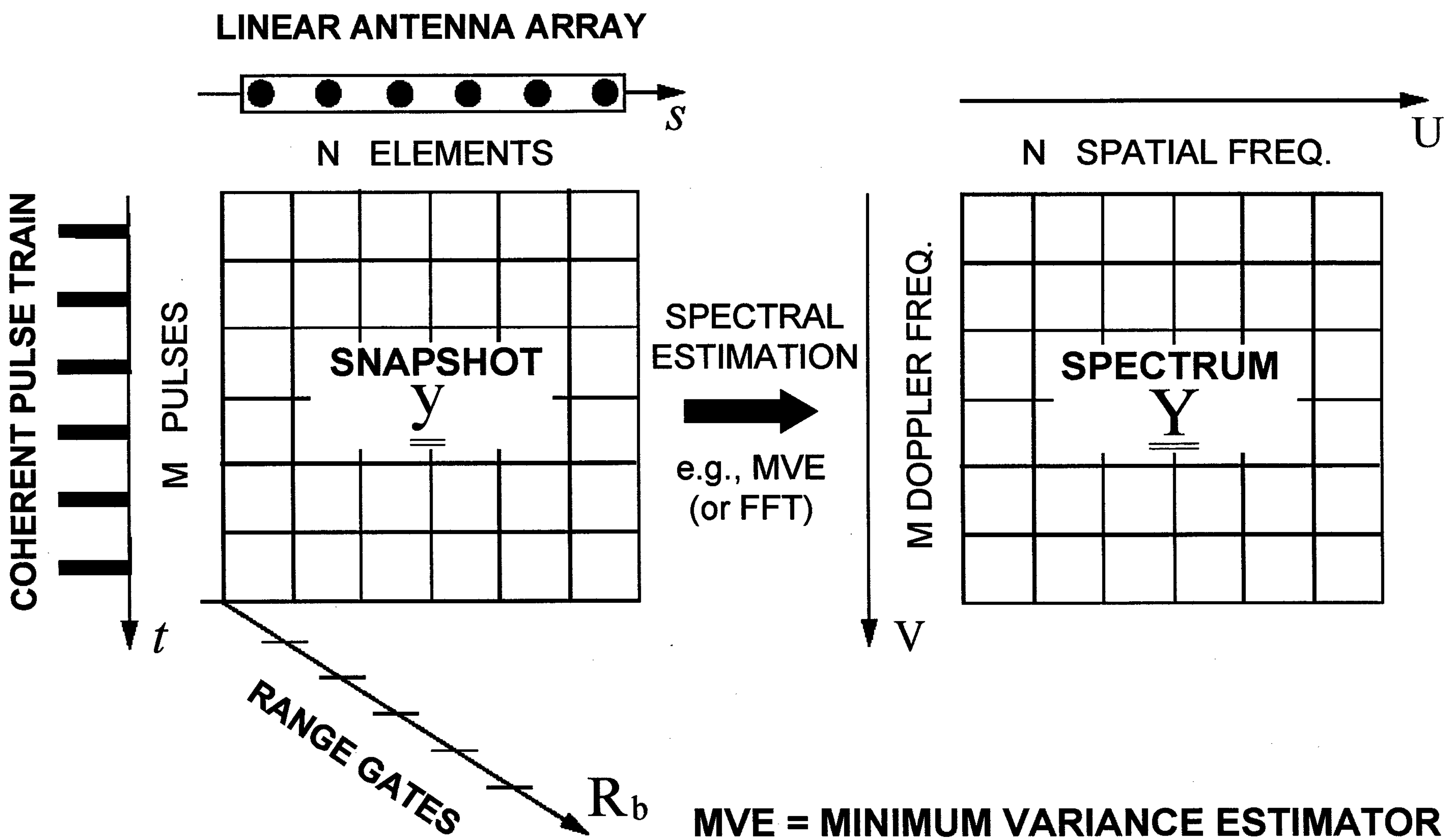
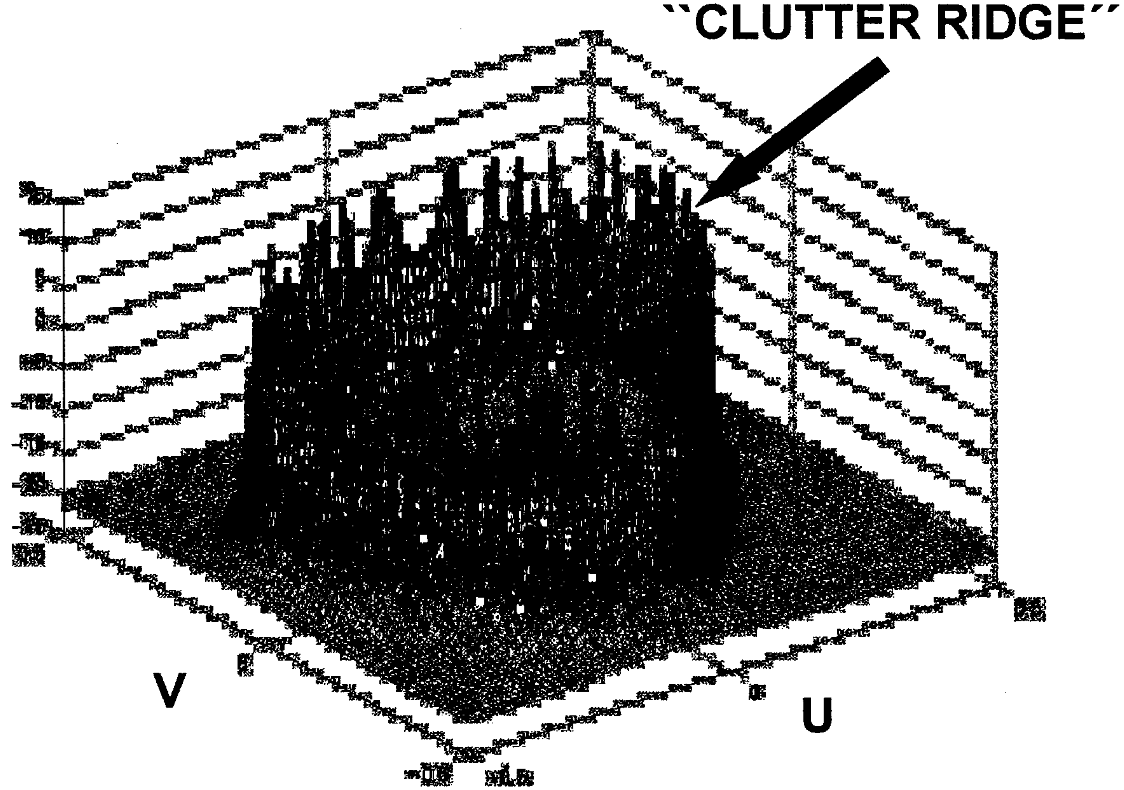
RADAR SNAPSHOT AND POWER SPECTRUM



MVE = MINIMUM VARIANCE ESTIMATOR

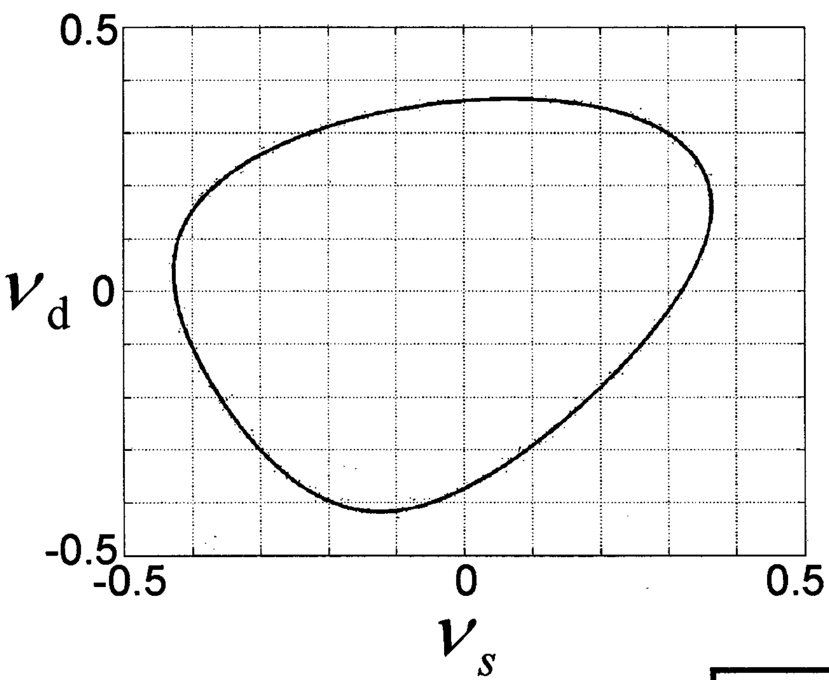
EXAMPLE POWER SPECTRUM: CLUTTER ONLY

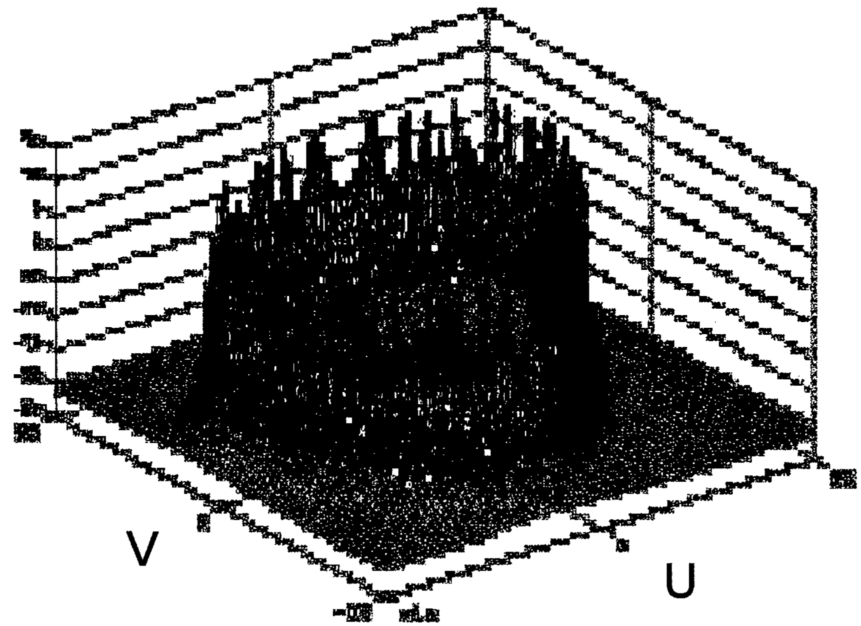


DOES THIS GRAPH TRIGGER ANY THOUGHT ?

THE KEY LINK BETWEEN THEORY AND MEASUREMENT

DD CURVE (THEORETICAL !) ⟷ **CLUTTER RIDGE (MEASURED!)**





$\nu_s \leftrightarrow U$

$\nu_d \leftrightarrow V$

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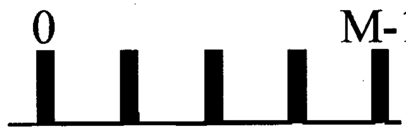
THE OPTIMUM STAP PROCESSOR



COHERENT PULSE TRAIN

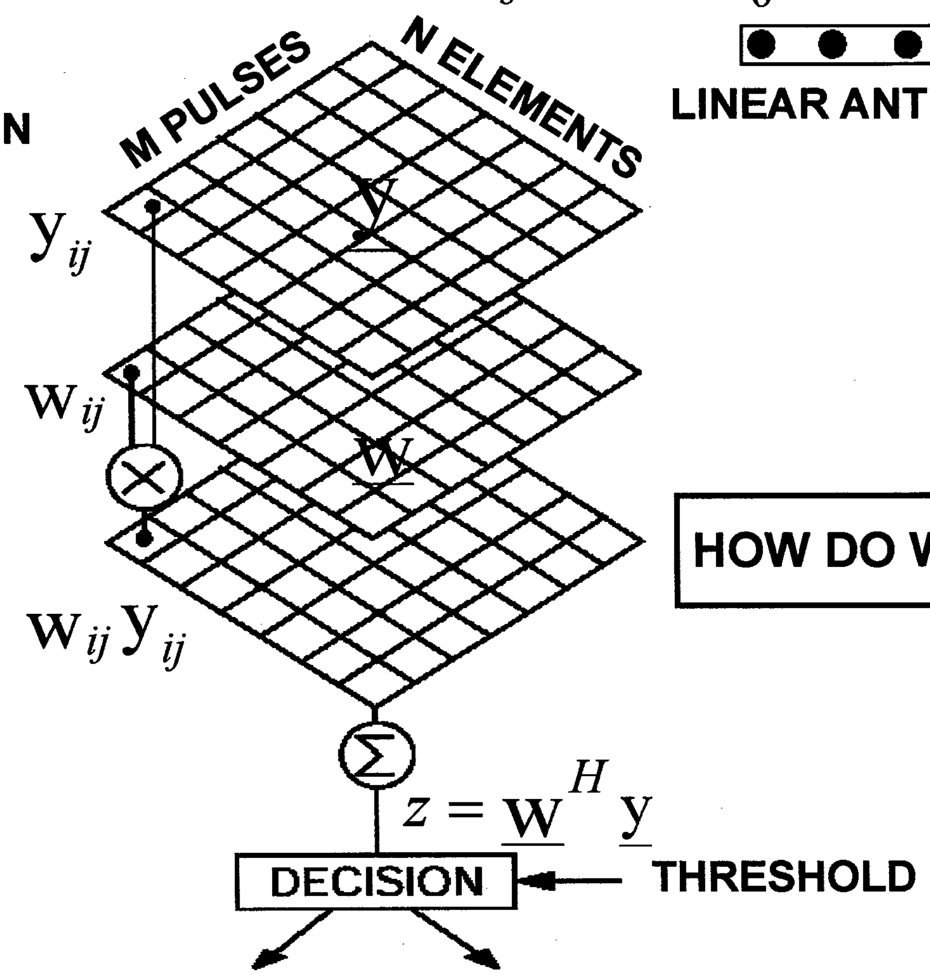
DESIRED WEIGHT

STEERING VECTOR

$$\underline{w} = \underline{\underline{R}}^{-1} \underline{v}$$

TRUE CLUTTER COVARIANCE MATRIX

AT EACH R_b



LINEAR ANTENNA ARRAY

HOW DO WE FIND $\underline{\underline{R}}$?

[redacted]

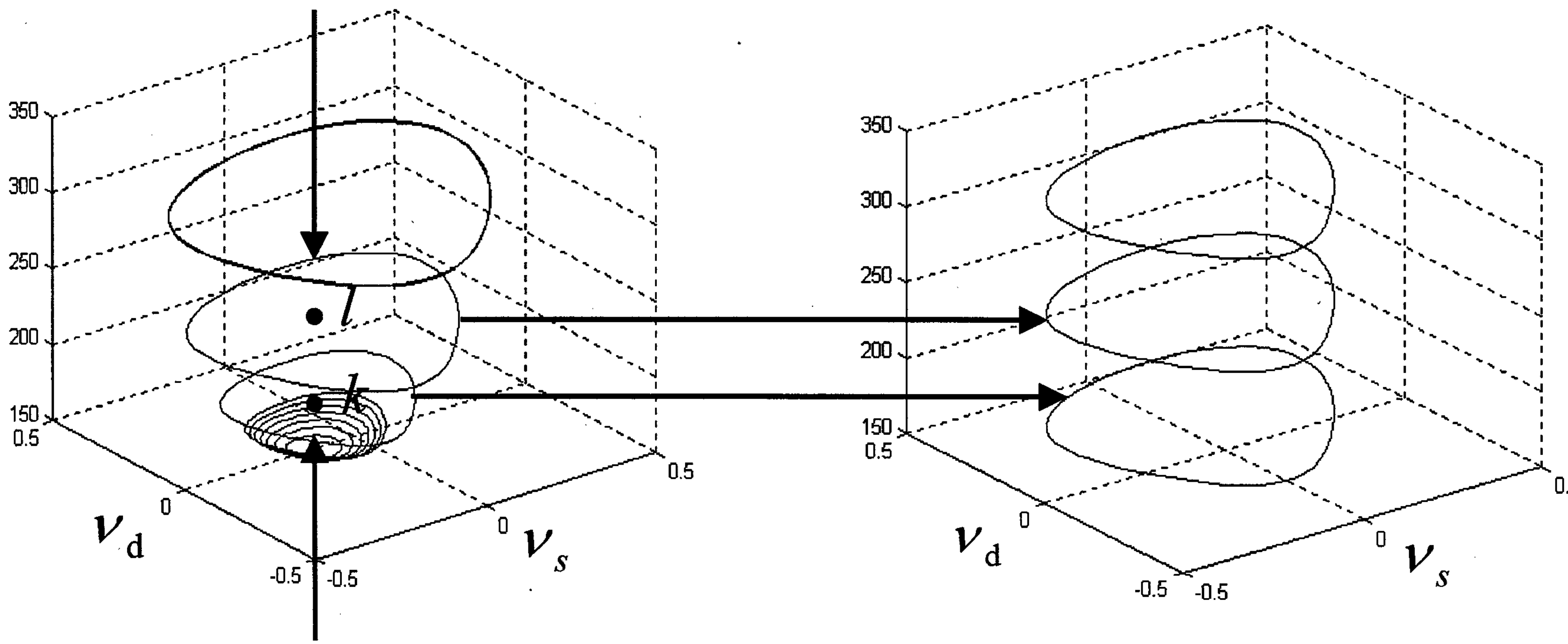
WHAT VALUE DO WE USE FOR $\underline{\underline{R}}$ IN $\underline{w} = \underline{\underline{R}}^{-1}\underline{v}$?

	THEORETICAL & BEST	PRACTICAL & WORST
COVARIANCE MATRIX $\underline{\underline{R}}(l)$	**<u>TRUE</u> ESTIMATE** $\underline{\underline{R}}(l) = E\{\underline{y}_k \underline{y}_k^H\}$	**<u>BIASED</u> ESTIMATE** $\hat{\underline{\underline{R}}}(l) = \frac{1}{N_l} \sum_{k \in S_l} \underline{\underline{R}}(k)$ $\underline{\underline{R}}(k) = \underline{y}_k \underline{y}_k^H$
PROCESSOR	OPTIMUM PROCESSOR (OP)	STRAIGHT-AVERAGING PROCESSOR (SA)

TO GET UNBIASED ESTIMATE OF $\underline{\underline{R}}(l)$,
WE MUST <u>ALIGN CLUTTER RIDGES</u> OF $\underline{\underline{R}}(k)$'s !

THE CRUX OF STAP: ALIGNING CLUTTER RIDGES, i.e., DD CURVES

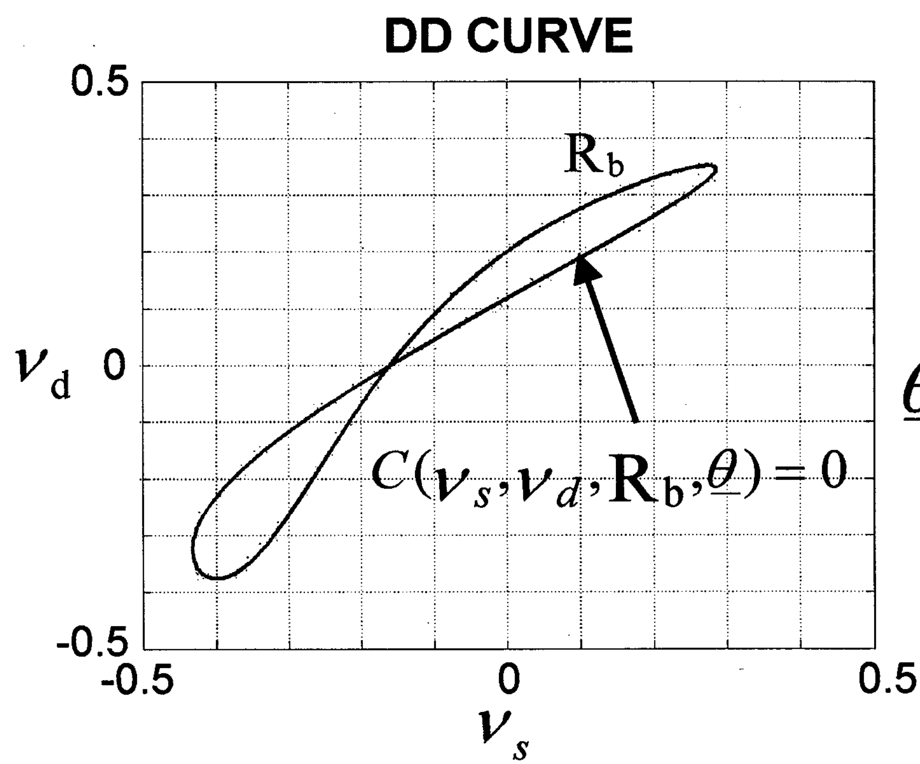
FIXED CURVE AT l (REFERENCE)



MOVING CURVE AT k

HOW DO WE ALIGN DD CURVES ?

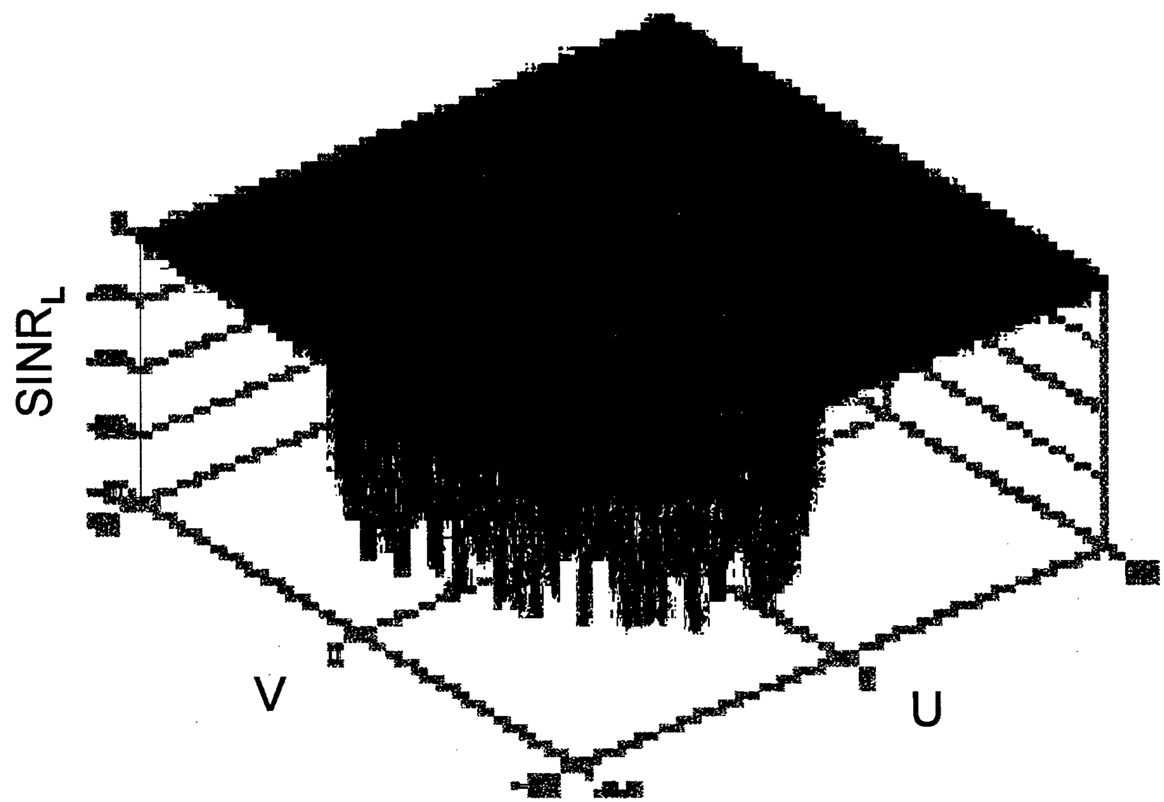
AN ABSOLUTE MUST:
A MATHEMATICAL THEORY OF DD CURVES



$$\underline{\theta} = \begin{cases} (x_R, y_R, z_R) = \text{RECEIVER POSITION} \\ \alpha_R = \text{RECEIVER VELOCITY ANGLE} \\ \delta = \text{ANTENNA ANGLE} \\ v_R = \text{RECEIVER VELOCITY} \\ v_T = \text{TRANSMITTER VELOCITY} \end{cases}$$

WE HAVE DEVELOPPED FORMULAS FOR ARBITRARY DD CURVES:
ONLY FOR THE MATHEMATICALLY-INCLINED !

HOW TO QUANTIFY PROCESSOR PERFORMANCE ? SINR LOSS

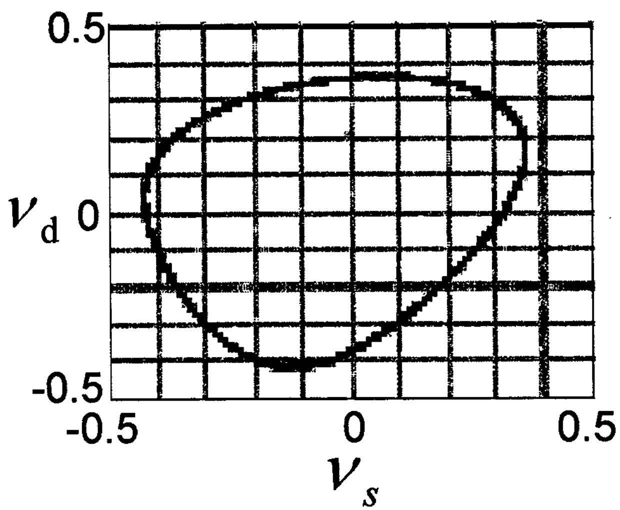


$$\mathrm{SINR}_L = \frac{\mathrm{SINR}}{\mathrm{SINR}_0} = \frac{|\underline{w}^H \underline{v}|^2}{(\underline{w}^H \underline{\underline{R}}\, \underline{w})(\underline{v}^H \underline{v})}$$

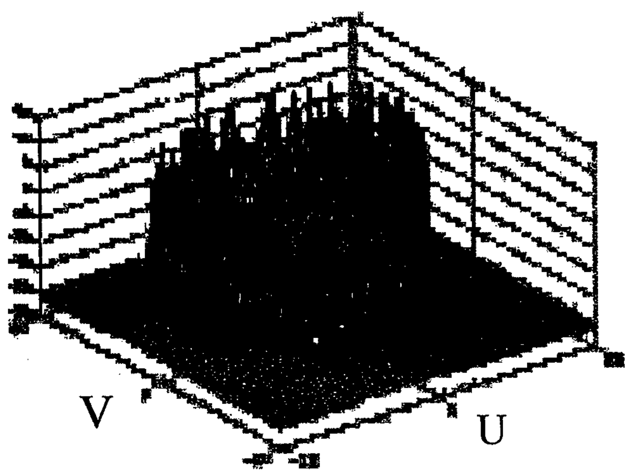
$$\underline{v}(\nu_s, \nu_d) \downarrow \mathrm{SINR}_L(\nu_s, \nu_d)$$

THE LINK BETWEEN THEORY, MEASUREMENT AND PERFORMANCE

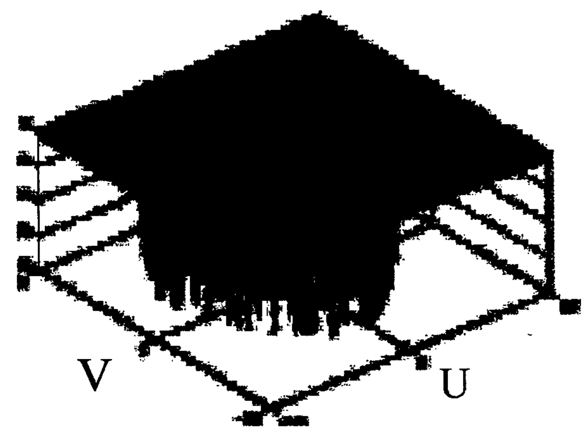
DD CURVE



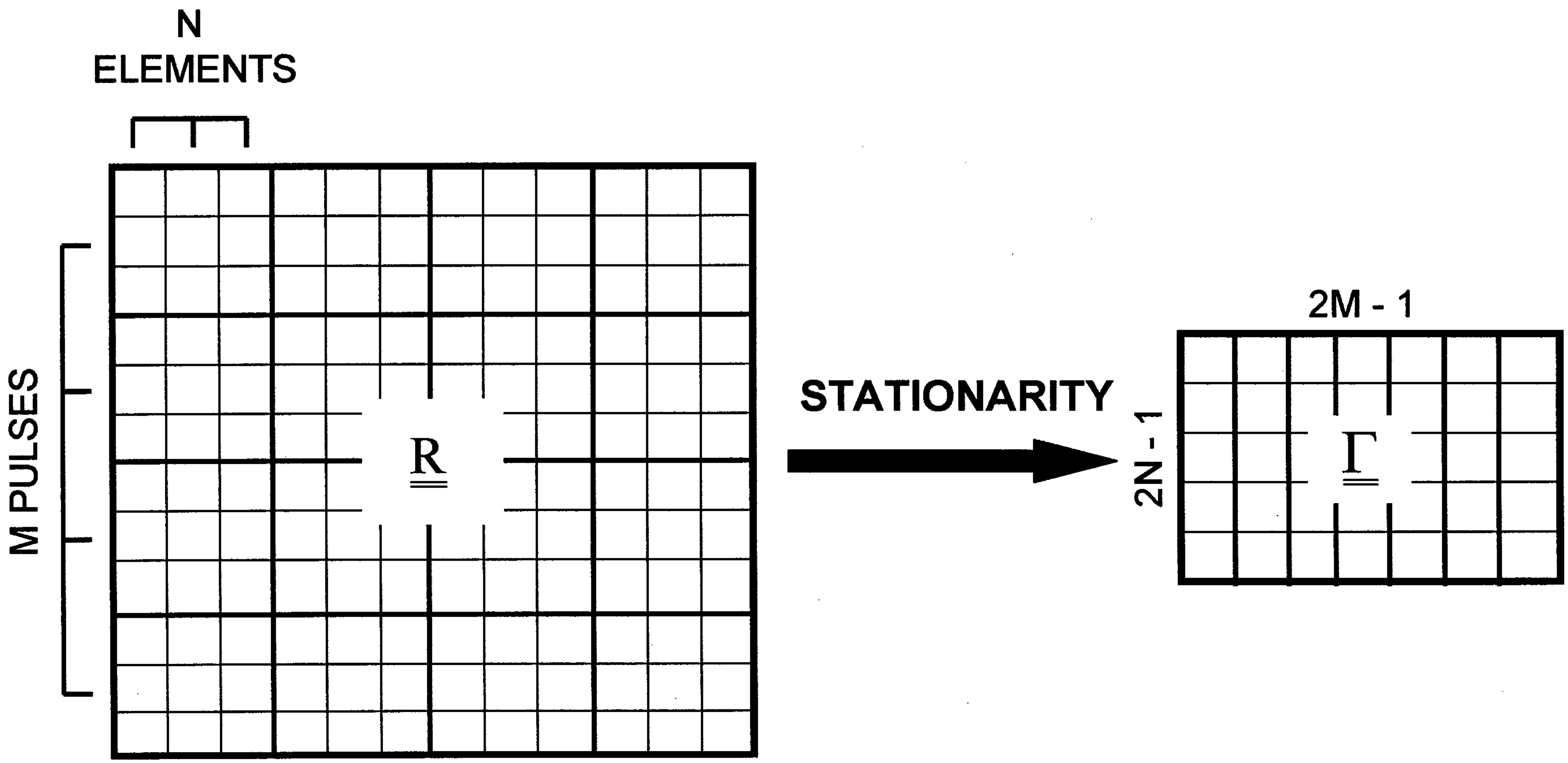
CLUTTER RIDGE (POWER SPECTRUM)



CLUTTER NOTCH (SINR LOSS)



ASSUMPTION OF STATIONARITY:
REDUCTION OF DIMENSIONALITY OF CLUTTER COVARIANCE MATRIX



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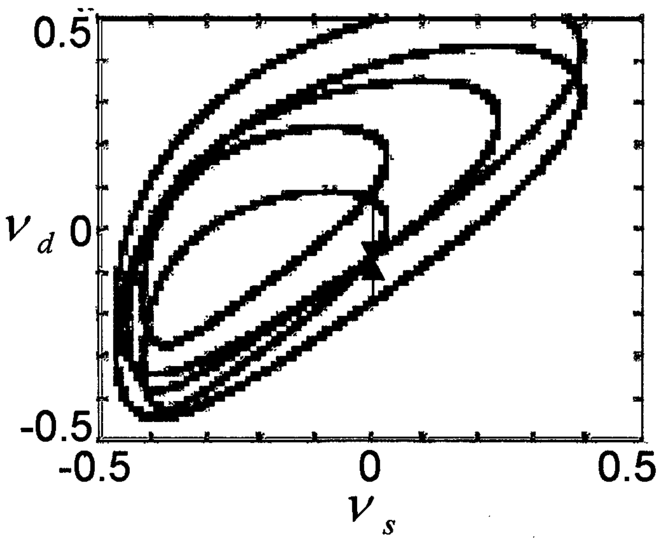
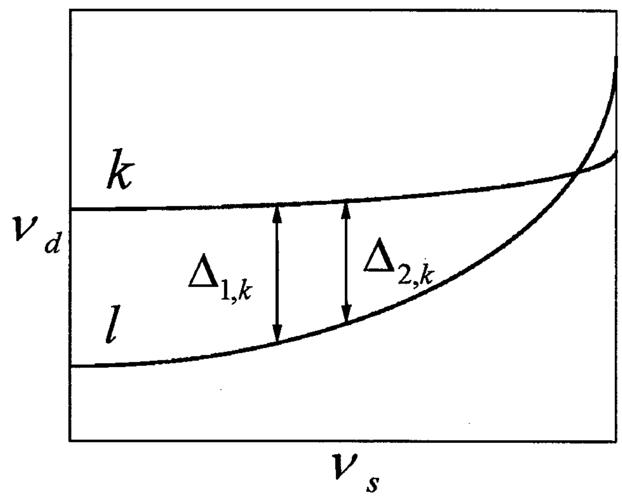
EXISTING RANGE-COMPENSATION METHODS: (1) PRINCIPLE

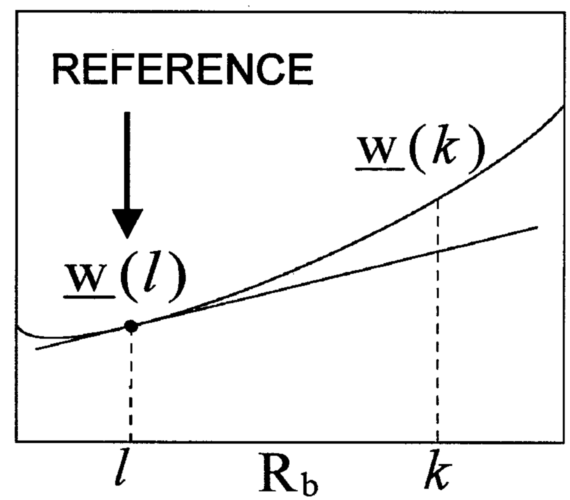
DOPPLER WARPING (DW)



HIGH-ORDER DOPPLER WARPING (HODW)



DERIVATIVE-BASED UPDATING (DBU)



WEIGHT CONSISTS IN A RANGE-DEPENDENT DOPPLER SHIFT

INDEPENDENT OF ν_s	DEPENDENT ON ν_s
Borsari, IEEE Radar Conf. (1998)	Pearson & Borsari, ASAP (2001)

WEIGHT GIVEN BY 1st-ORDER TAYLOR SERIES

$$\underline{w}(k) = \underline{w}(l) + (k - l)\dot{\underline{w}}(l)$$

Haynard (1996), Zatman & Kogon (2000), Zatman(2001)

EXISTING RANGE-COMPENSATION METHODS: (2) COMPARISON

	DW	HODW	DBU
+	• SIMPLE IMPLEMENTATION	• NEARLY-PERFECT COMPENSATION	• PARAMETERS NOT REQUIRED
—	• POOR PERFORMANCE FOR BS CONFIGURATION • PARAMETERS REQUIRED	• COMPLICATED DOPPLER FILTERING • PARAMETERS REQUIRED	• GOOD PERFORMANCE FOR SOME BS CONFIGURATIONS • TWICE AS MANY DOF REQUIRED

OUR GOAL : GENERAL BS CONFIGURATIONS, UNKNOWN PARAMETERS, LOW COMPLEXITY WITHOUT ANY INCREASE IN NUMBER OF DOF

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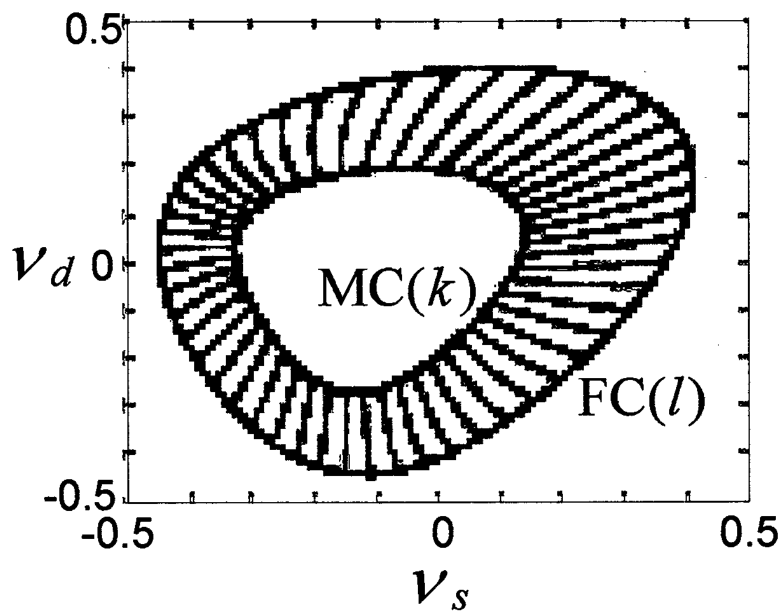
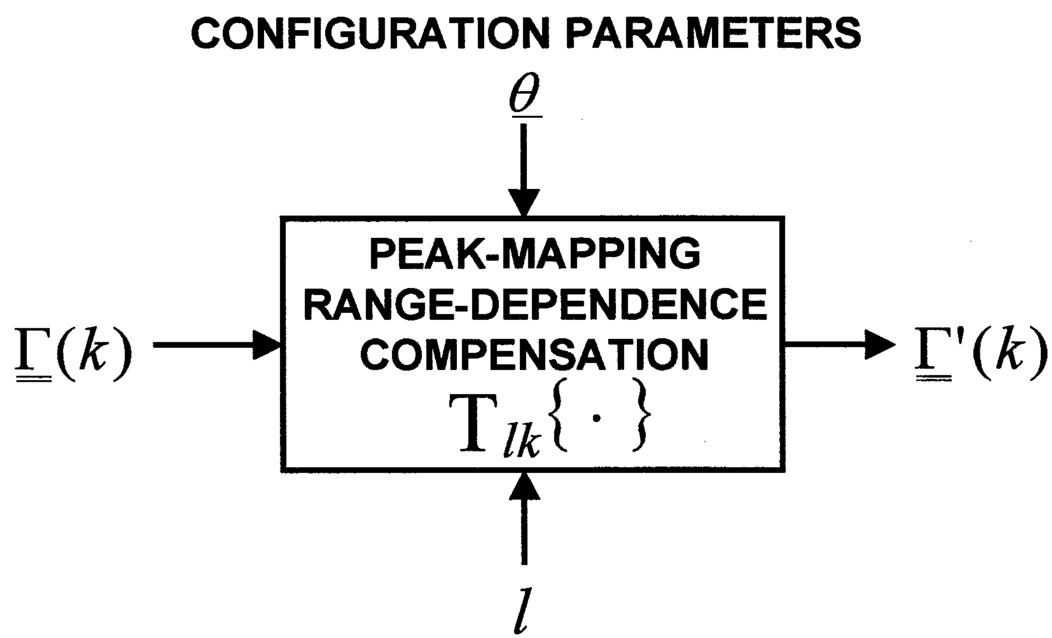
PEAK-MAPPING RANGE-DEPENDENCE COMPENSATION: (1) Principle





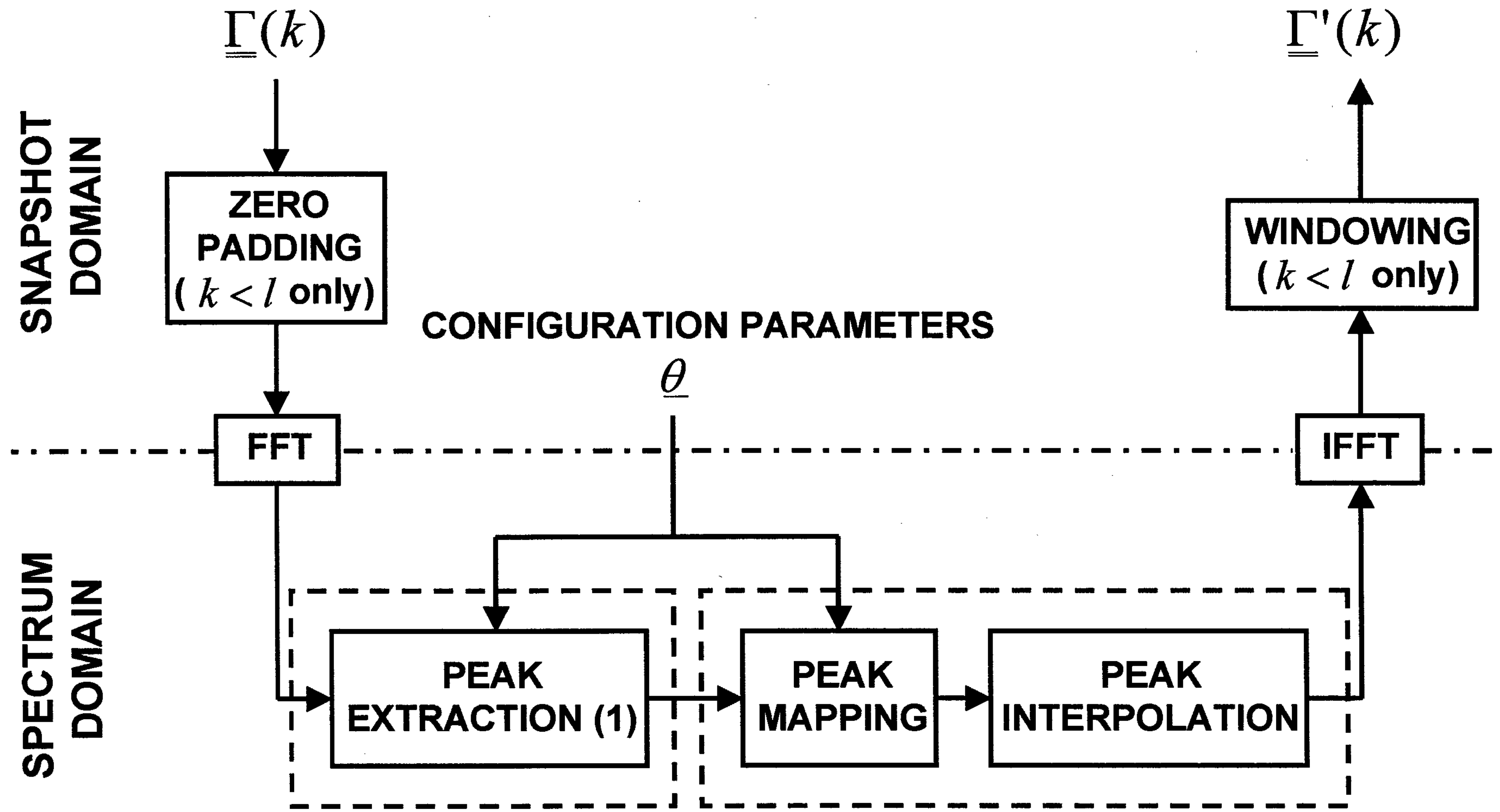
$\mathrm{MC}(k)$ = MOVING CURVE AT RANGE GATE k

$\mathrm{FC}(l)$ = FIXED CURVE AT REFERENCE RANGE GATE l

$$\hat{\underline{\underline{\Gamma}}}(l) = \frac{1}{N_l} \sum_{k \in S_l} T_{lk}^{\Gamma}\{\underline{\underline{\Gamma}}(k)\}$$

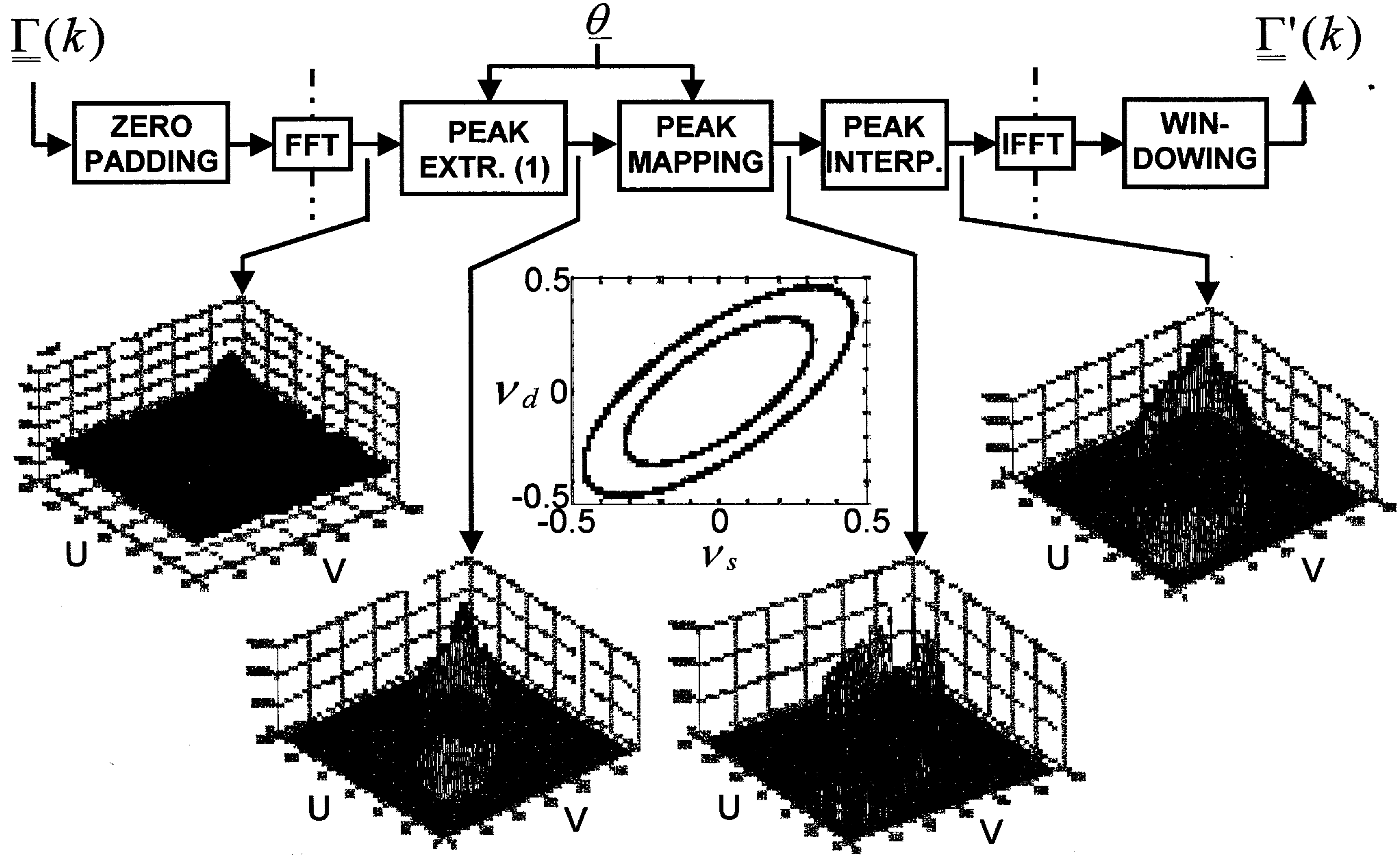
HOW DO WE FIND T_{lk}^{Γ} FOR ALL k AND l ?

PEAK-MAPPING RANGE-DEPENDENCE COMPENSATION: (2) System

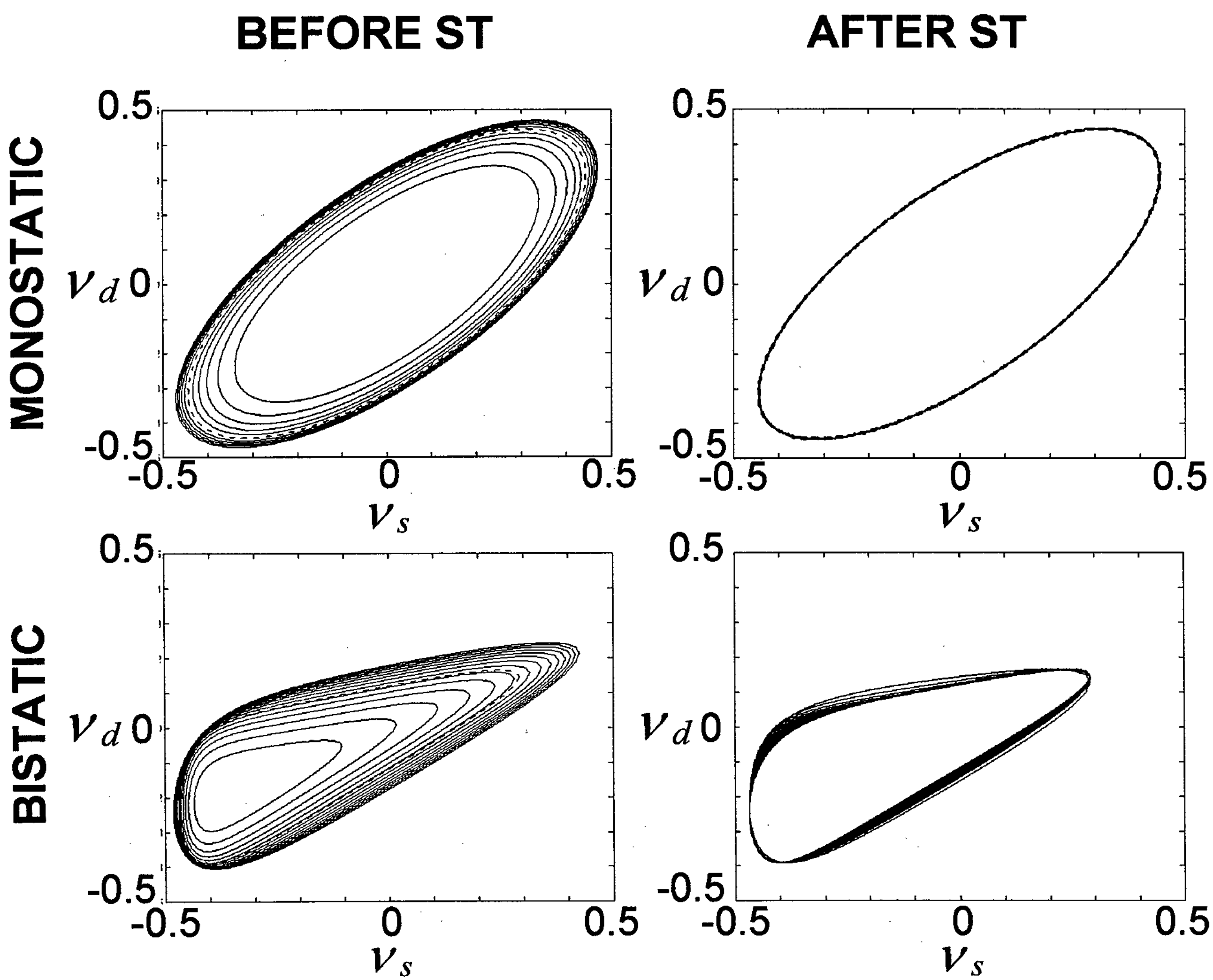


WE PROPOSE THREE PEAK-MAPPINGS METHODS

PEAK-MAPPING BY SCALING TRANSFORMATION (ST): (1) PRINCIPLE



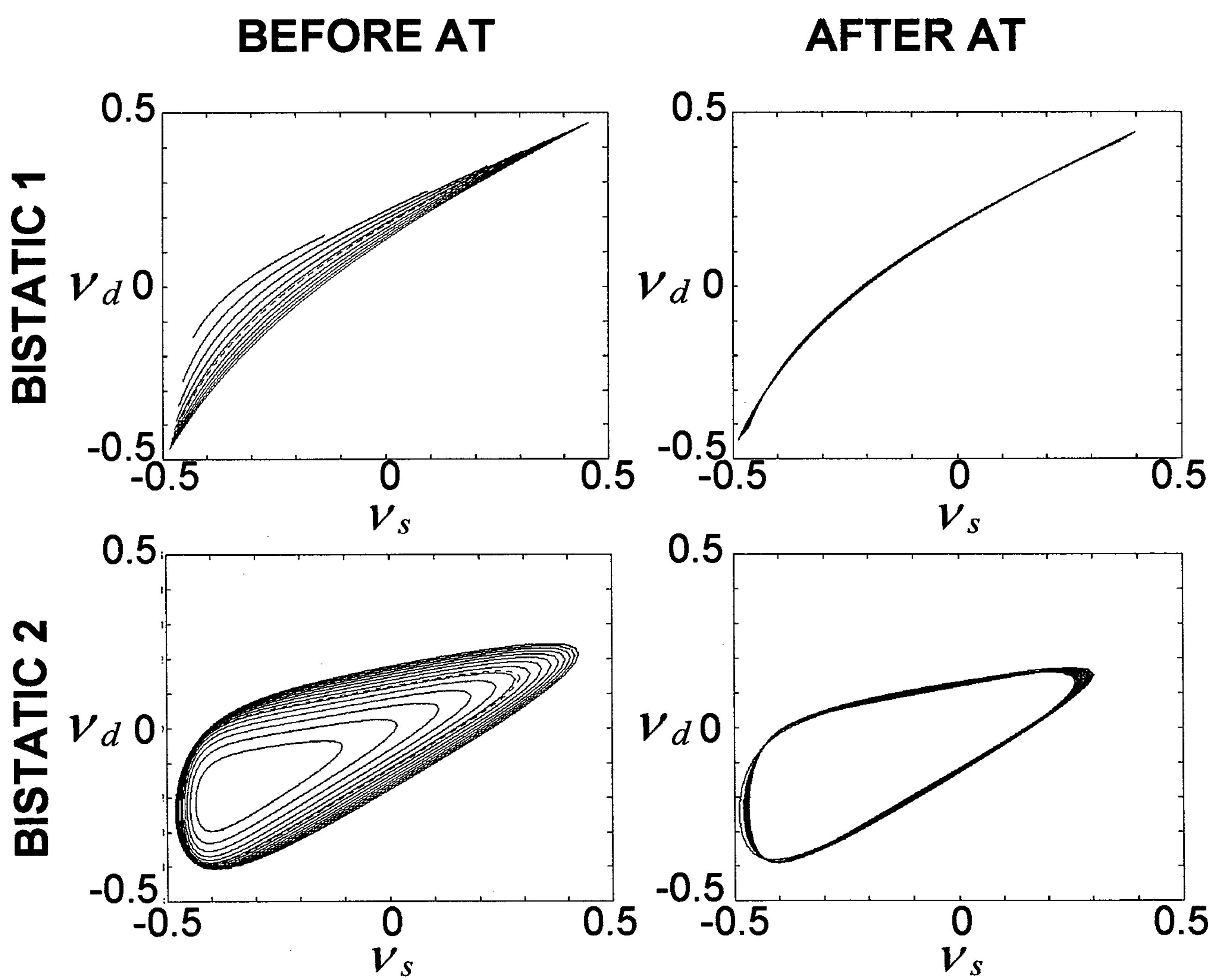
PEAK-MAPPING BY SCALING TRANSFORMATION (ST): (2) PERFORMANCE



WORKS ONLY FOR MONOSTATIC CONFIGURATIONS

HOW DO WE EXTEND RANGE OF APPLICABILITY ?

PEAK-MAPPING BY AFFINE TRANSFORMATION (AT): PRINCIPLE

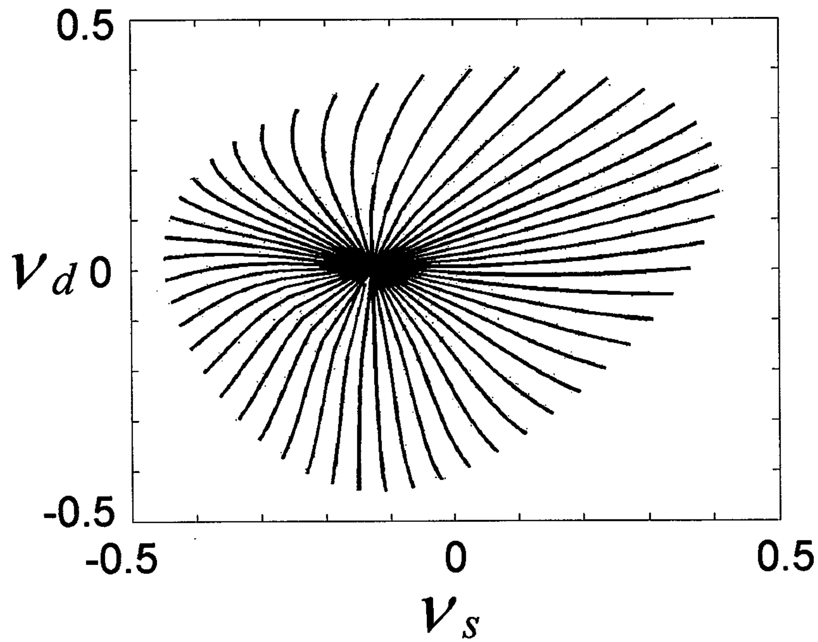


WORKS ONLY FOR MONOSTATIC AND SOME BISTATIC CONFIGURATIONS

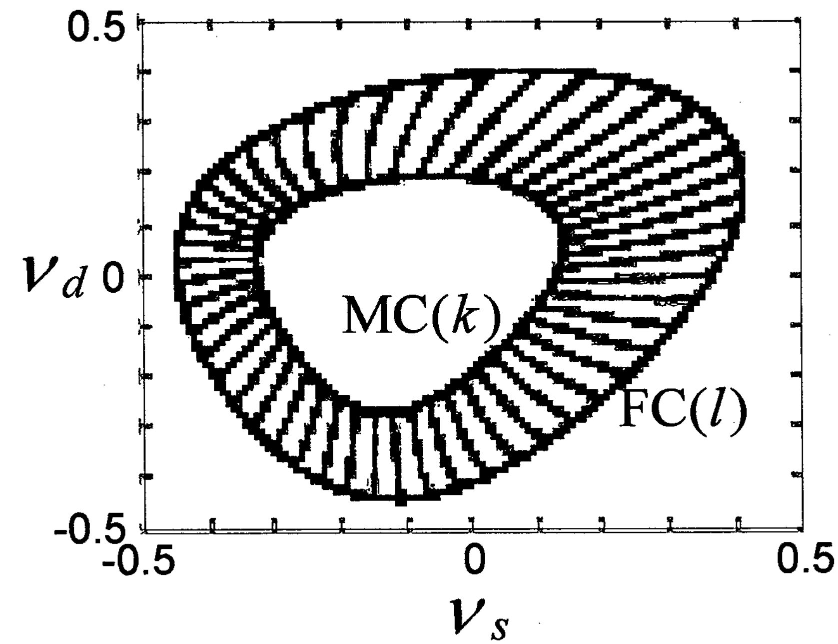
HOW DO WE EXTEND RANGE OF APPLICABILITY ?

PEAK-MAPPING BY WARPING TRANSFORMATION (WT): (1) PRINCIPLE

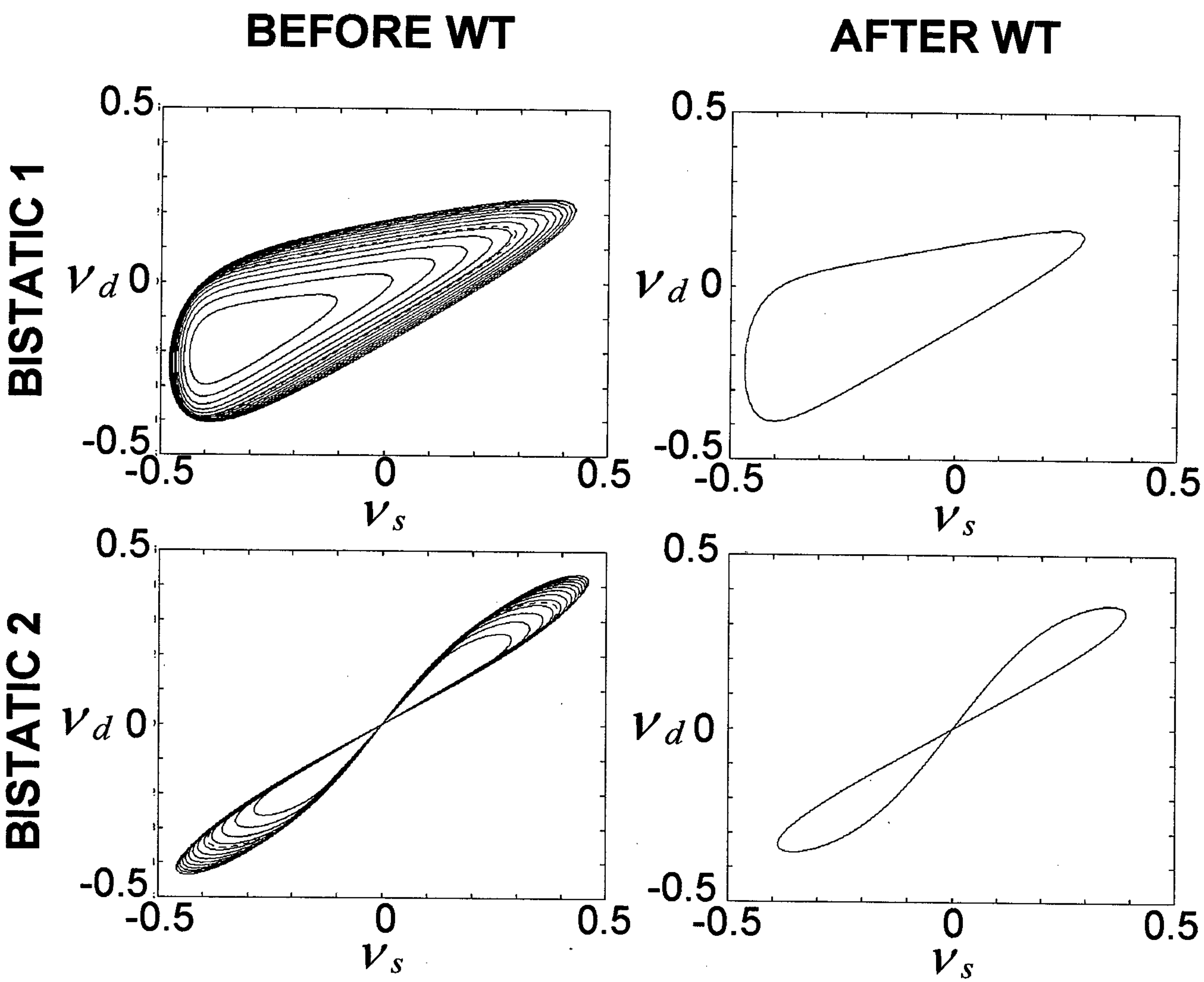
EXAMPLE FLOW LINES



WARPING TRANSFORMATION



PEAK-MAPPING BY WARPING TRANSFORMATION (WT): (2) PERFORMANCE

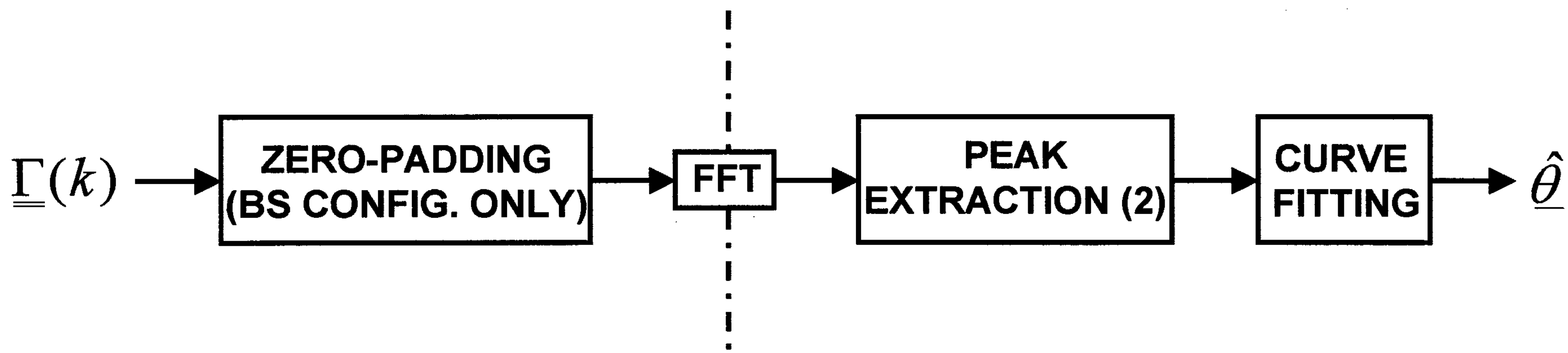


WORKS FOR ALL MONOSTATIC AND BISTATIC CONFIGURATIONS

↓

HOW DO WE FIND CONFIGURATION PARAMETERS IF UNKNOWN ?

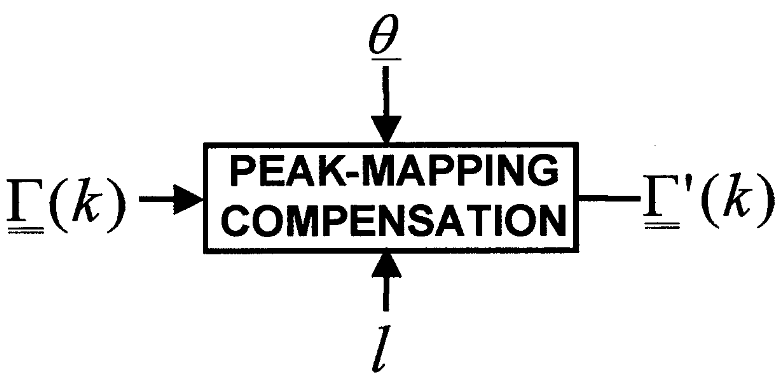
HOW DO WE FIND THE CONFIGURATION PARAMETERS ?



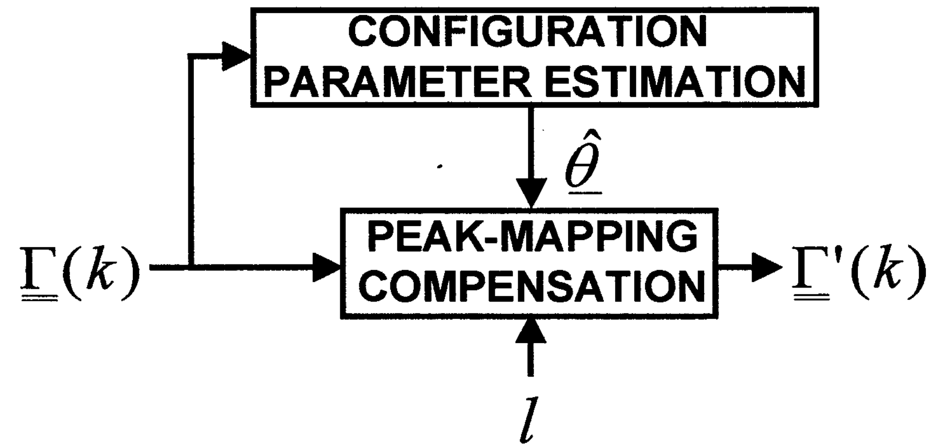
CONFIGURATION	PEAK EXTRACTION (2)	CURVE FITTING
MS	THRESHOLDING	SIMPLE MMSE
BS	WATERSHED SEGM. (Image processing)	DIFFICULT MMSE (Theory of DD curves)

RANGE COMPENSATION METHODS COME IN TWO TYPES AND SIX FLAVORS!

OPEN-LOOP (OL)

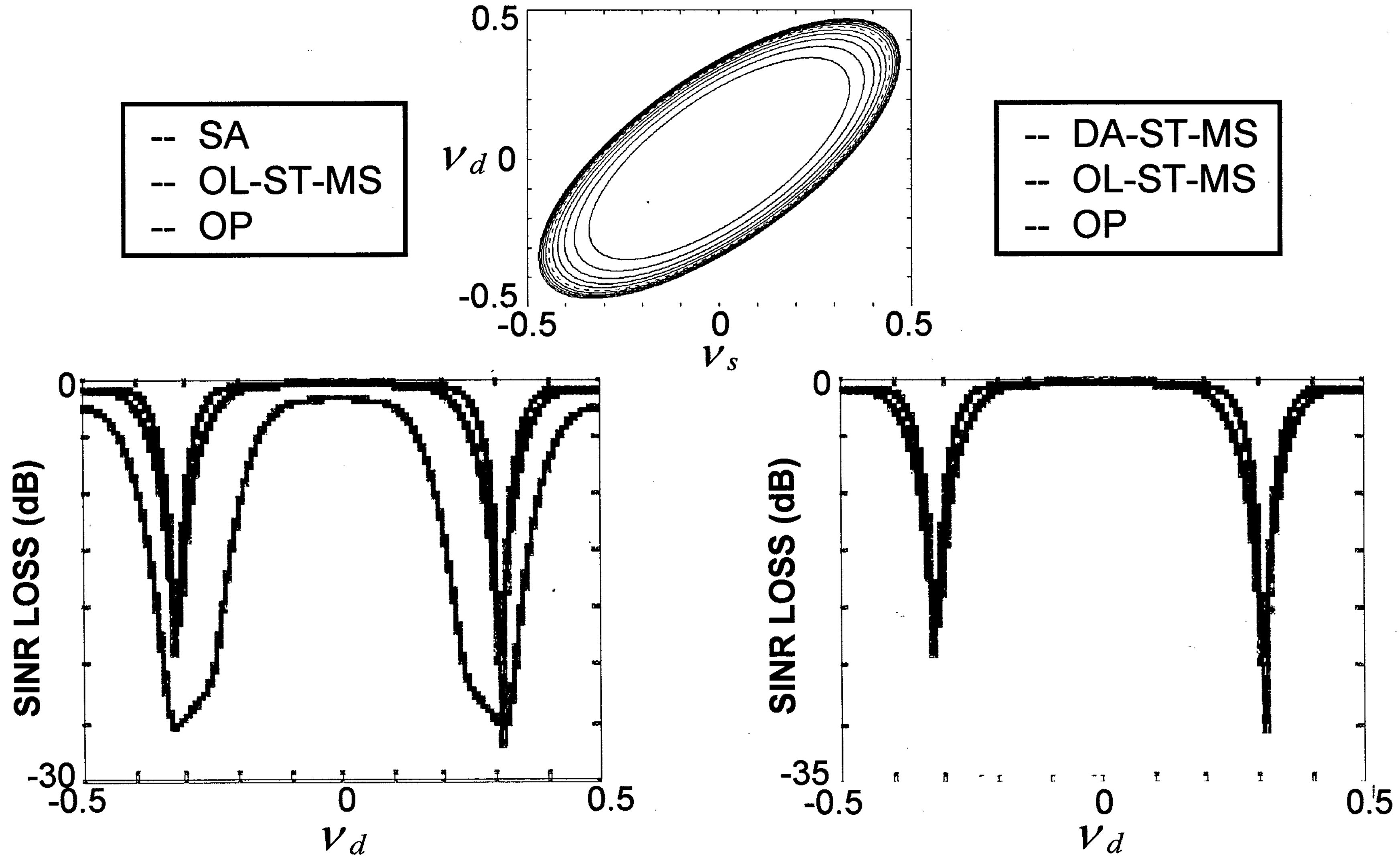


DATA-ADAPTIVE (DA)

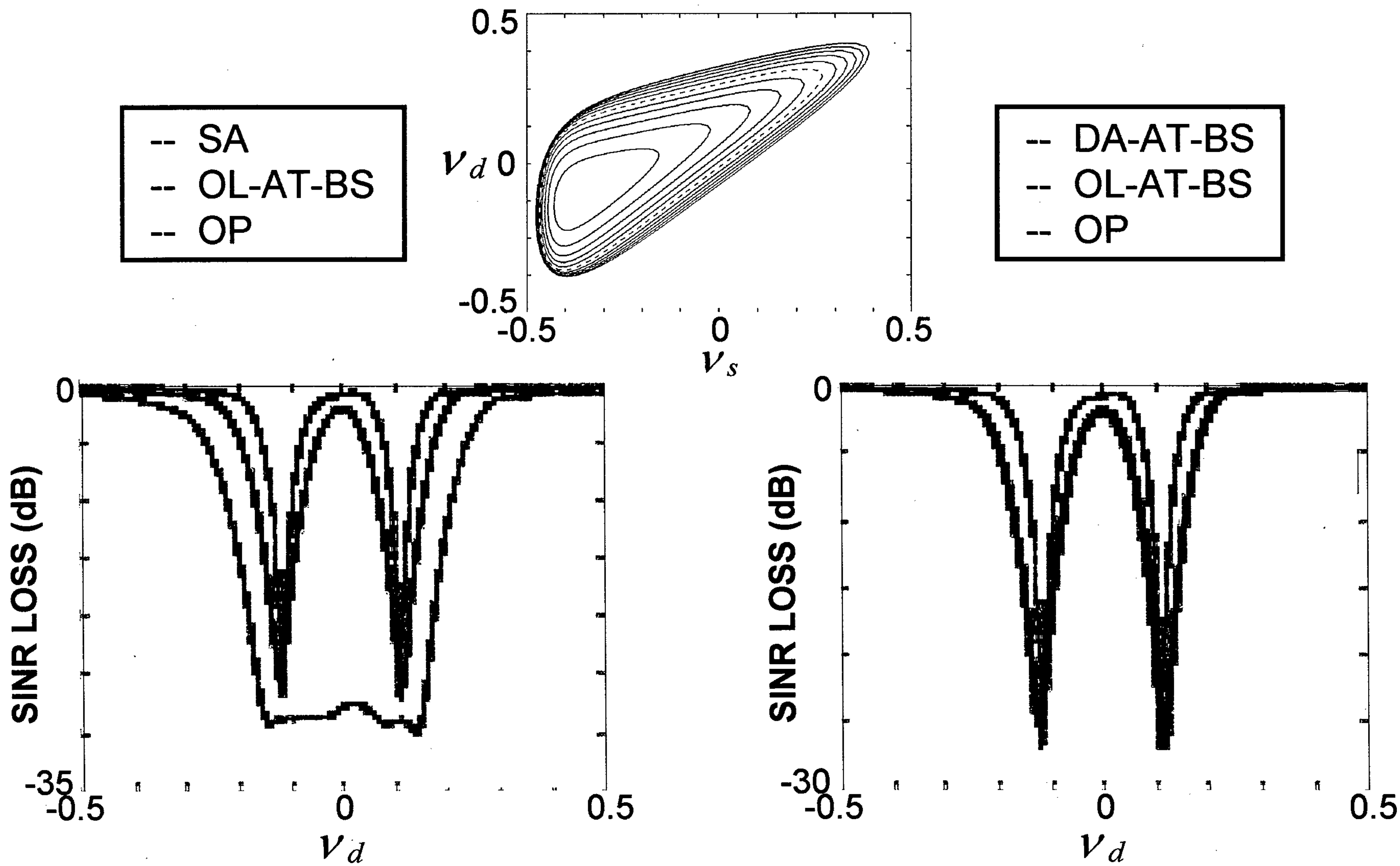


PEAK-MAPPING COMPENSATION	OPEN-LOOP (OL)	DATA-ADAPTIVE (DA)
SCALING TRANSFORMATION (MS)	OL-ST-MS	DA-ST-MS
AFFINE TRANSFORMATION (BS)	OL-AT-BS	DA-AT-BS
WARPING TRANSFORMATION (BS)	OL-WT-BS	DA-WT-BS

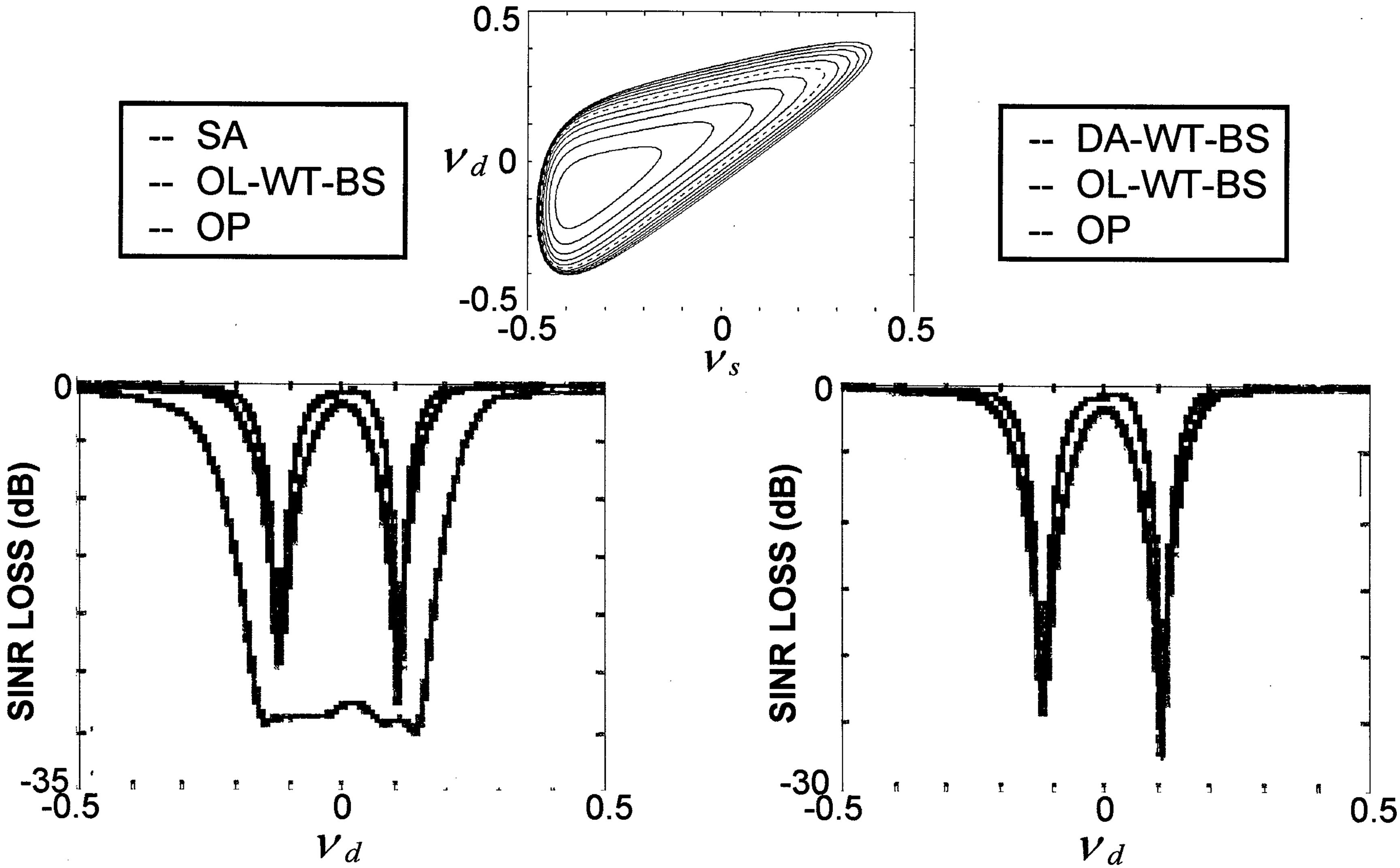
PERFORMANCE COMPARISON: (1) ST-MS



PERFORMANCE COMPARISON:
(2) AT-BS

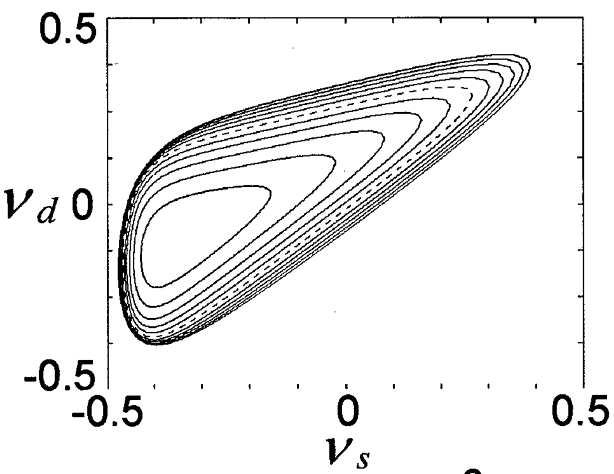


PERFORMANCE COMPARISON:
(3) WT-BS

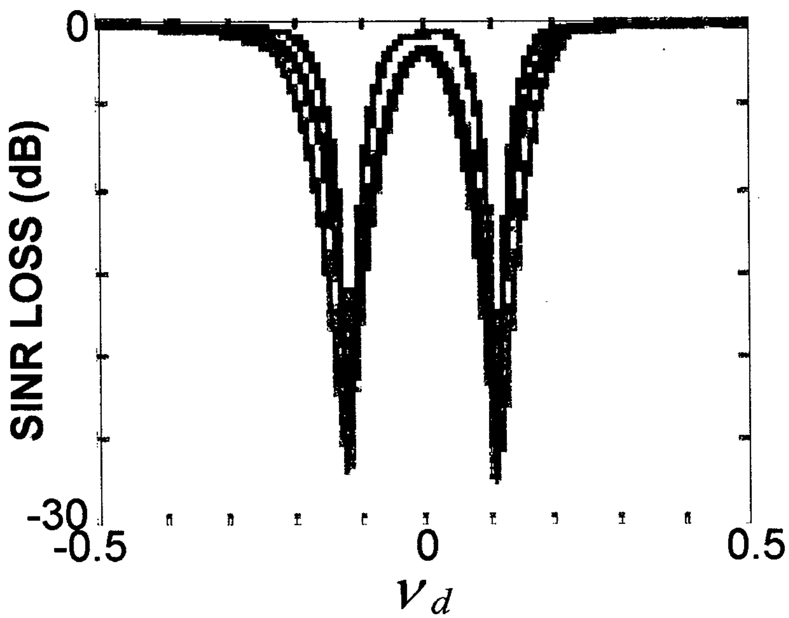


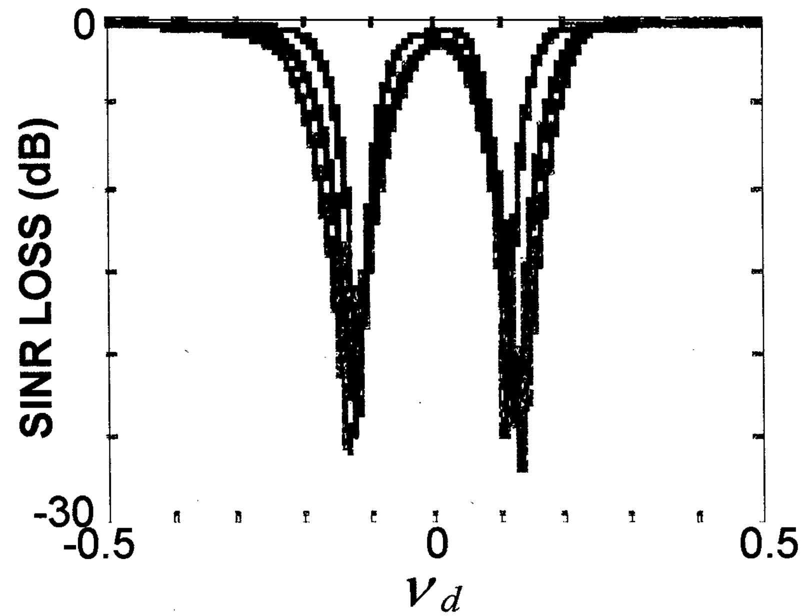
PERFORMANCE COMPARISON:
(4) AT vs BT

-- OL-AT-BS
-- OL-WT-BS
-- OP

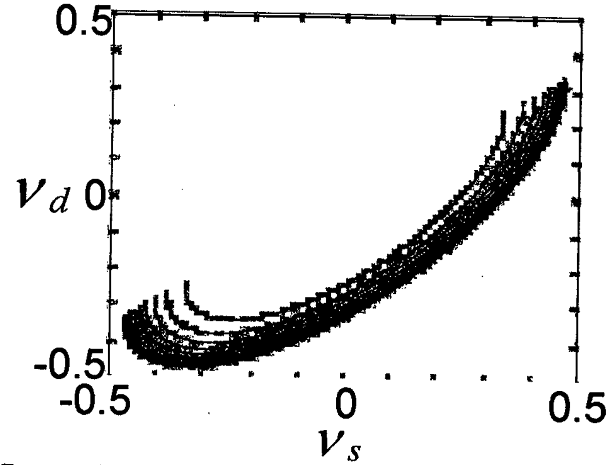


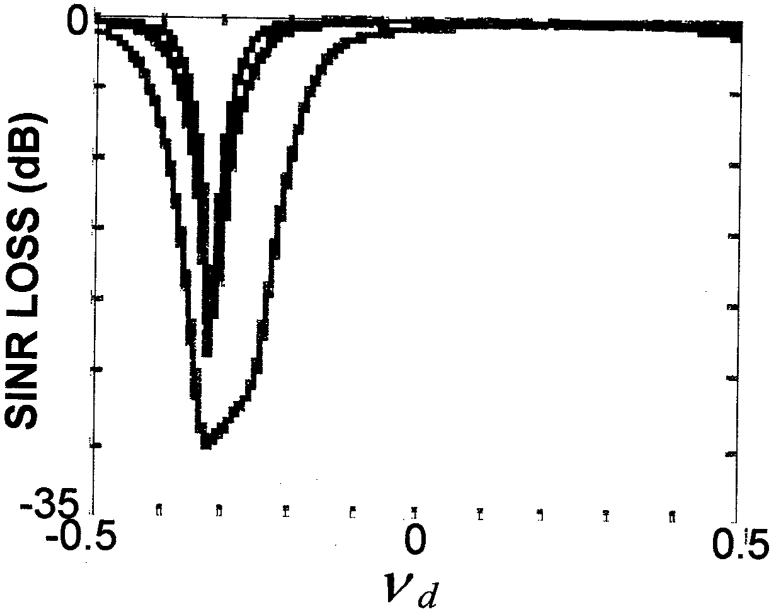
-- DA-AT-BS
-- DA-WT-BS
-- OP





PERFORMANCE COMPARISON: (5) DIRECTIVE SENSORS, MONOSTATIC





- SAME RESULTS FOR BS CONFIGURATIONS WITH DIRECTIVE SENSORS
- POOR PERFORMANCE FOR BS DA METHODS WITH DIRECTIVE SENSORS

OUTLINE

- INTRODUCTION
- CONFIGURATIONS AND SIGNALS
- RANGE-DEPENDENCE PROBLEM
- SNAPSHOT AND SPECTRUM
- STAP PROCESSOR
- EXISTING COMPENSATION METHODS
- NEW REGISTRATION-BASED METHODS
- SUMMARY

SUMMARY

- **RANGE-DEPENDENCE OF BS CLUTTER SPECTRUM MAKES BS CLUTTER REJECTION A CHALLENGE IN STAP**

- **WE REVIEWED EXISTING COMPENSATION METHODS**
  - DOPPLER WARPING (DW)
  - HIGH-ORDER DOPPLER WARPING (HODW)
    - Configuration parameters required
  - DERIVATIVE-BASED UPDATING (DBU)
    - Doubling of number of DOF

- **WE PROPOSED NEW REGISTRATION-BASED COMPENSATION METHODS**

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- Nearly perfect compensation for all MS and BS configurations
- Configuration parameters not required
- No increase of number of DOF

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- High computational load
- Complex implementation
- Robustness