Application of MUSIC, ESPRIT and SAGE Algorithms for Narrowband Signal Detection and Localization

Franz A. de Leon
MS EE (C&C)

Joel S. Marciano, Ph.D.
Thesis Adviser

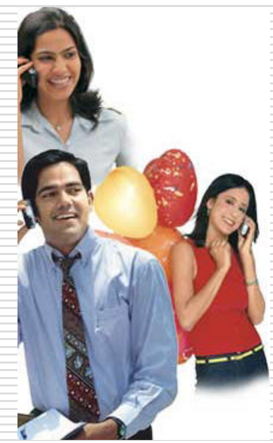
Thesis Proposal Presentation
UP EEE

Outline

- Introduction
- Statement of the Problem
- Objectives
- Methodology
- Schedule

Mobile Communications

- Demands
  - Better coverage
  - Improved capacity
  - Better QoS



Mobile Communications

- Challenges
  - Interference
    - Contamination of an information-bearing signal by another similar signal
  - Fading
    - Change in the attenuation of the communications channel

Mobile Communications

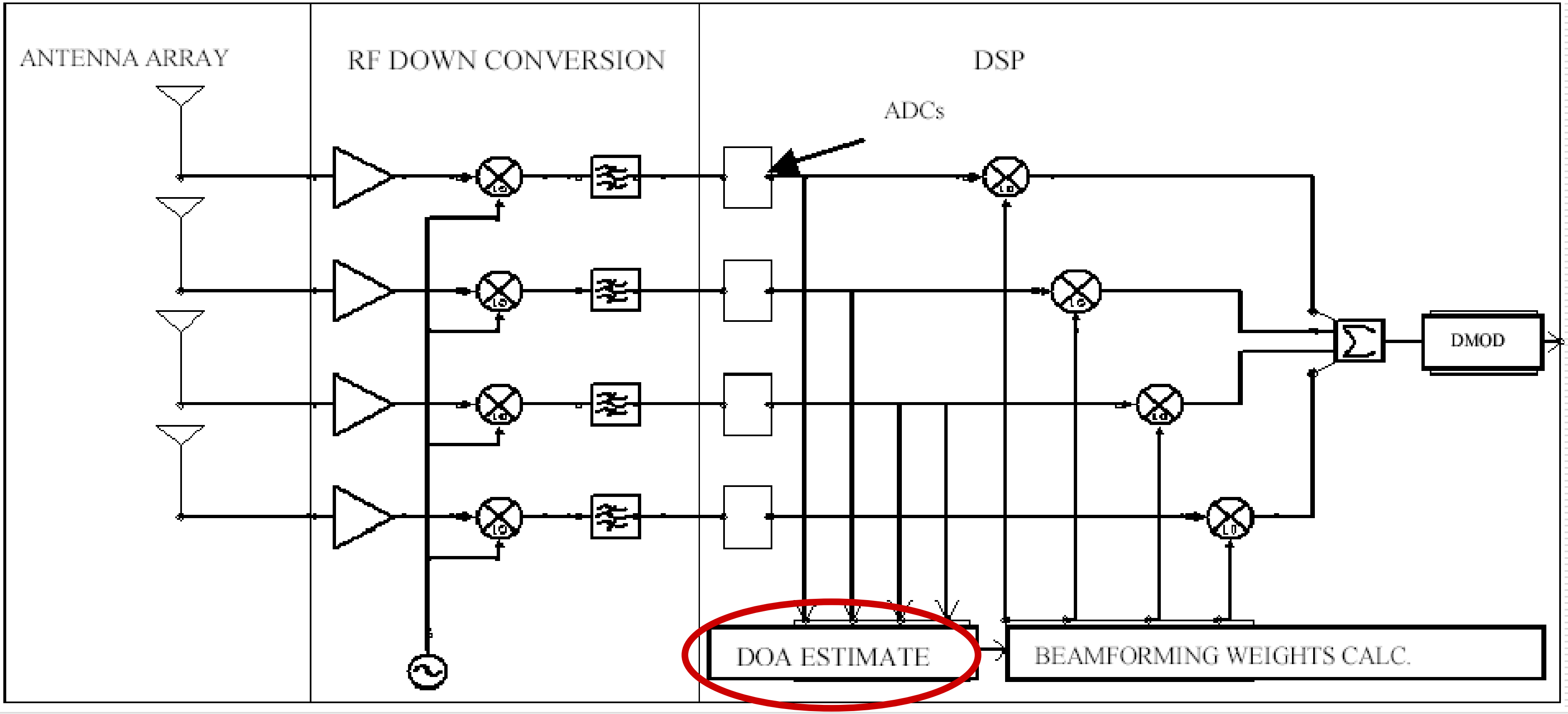
- Challenges
  - Multipath
    - Describes propagation that arrives at a receiver having traveled over different paths
  - Limited Capacity
    - Limitation on the bandwidth

Conventional Antennas vs Smart Antennas

- Conventional Antennas
  - Omnidirectional transmission
  - Prone to interference

- Smart Antennas
  - Focus transmission and receive energy on desired directions
  - Place nulls on unwanted interference

Smart Antenna Architecture



Direction of Arrival Estimation

- Conventional Methods
  - Delay-and-Sum Method
  - Capon's Minimum Variance Method
- Subspace-based Methods
  - MUSIC
  - ESPRIT
- Maximum-likelihood Methods
  - Alternating Projection Algorithm
  - SAGE

MUSIC

- Multiple Signal Classification

- Schmidt R.O., “Multiple Emitter Location and Signal Parameter stimation”, IEEE Trans. On Antennas and Propagation, Vol. AP-34, No. 3, 1986.

- Subspace method based on the eigenvector decomposition of the covariance matrix

$$\mathbf{R}_{xx} = E\left(\mathbf{x}(t)\mathbf{x}^H(t)\right)$$

- Covariance matrix with uncorrelated noise

$$\mathbf{R}_{xx} = \mathbf{A}E\left(\mathbf{s}(t)\mathbf{s}^H(t)\right)\mathbf{A} + E\left(\mathbf{n}(t)\mathbf{n}^H(t)\right)$$

MUSIC

- Performing SVD on the covariance matix

$$\mathbf{R}_{xx} = \mathbf{U}\Lambda\mathbf{U}^H$$

- The eigenvalues can be classified as coming from the source, interference and noise

- The smallest eigenvalues are

$$\lambda_{L+1} = \lambda_{L+2} = \ldots = \lambda_N = \sigma^2$$

- The eigenvectors corresponding to the smallest eigenvalues span the noise subspace

MUSIC

- Projecting the array factor to the noise subspace produces the vector

$$\mathbf{z} = \mathbf{P}_{\mathbf{A}}^{\perp}\mathbf{a}(\theta) \qquad \mathbf{P}_{\mathbf{A}}^{\perp} = \mathbf{I} - \mathbf{A}\mathbf{A}^{+} = \mathbf{U}_n\left(\mathbf{U}_n^H\mathbf{U}_n\right)^{-1}\mathbf{U}_n^H = \mathbf{U}_n\mathbf{U}_n^H$$

- Searching the magnitude squared of the projection vector where it is zero determines the DoA of the signals

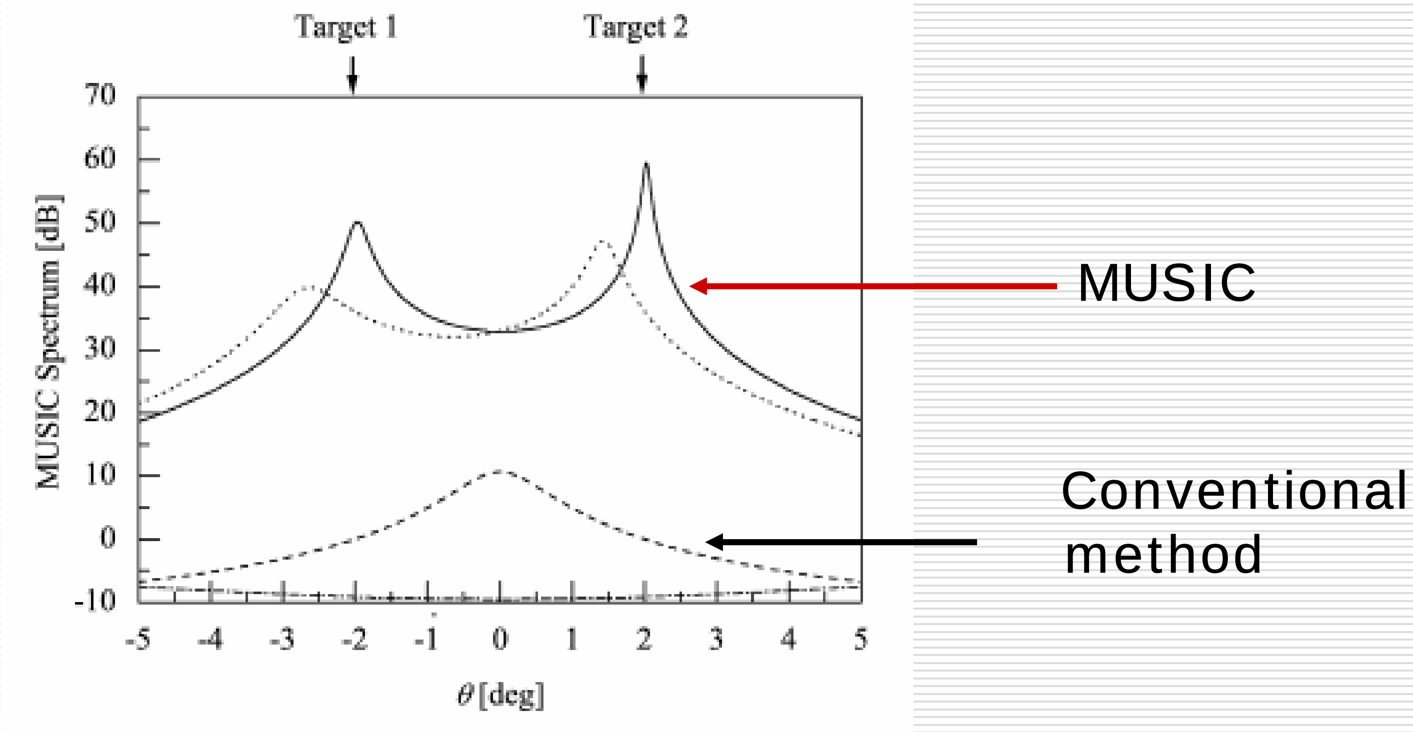
$$f(\theta) = \mathbf{z}^H\mathbf{z} = \mathbf{a}^H(\theta)\mathbf{P}_{\mathbf{A}}^{\perp H}\mathbf{P}_{\mathbf{A}}^{\perp}\mathbf{a}(\theta) = \mathbf{a}^H(\theta)\mathbf{U}_n\mathbf{U}_n^H\mathbf{a}(\theta)$$

- Advantage: Provides high resolution DoA estimate

- Disadvantage: MUSIC breaks down for correlated signals

MUSIC

- Simulated MUSIC Spectrum



ESPRIT

- Estimation of Signal Parameters via Rotational Invariance Techniques

- Paulraj A., Roy R., Kailath., “Estimation of Signal Parameters via Rotational Invariance Tchniques-ESPRIT”, IEEE Trans. On Acoustics Speech, and Signal Processing, Vol. 37, No. 1, January 1989.

- Subspace method that exploits the rotational invariance of the signal subspaces of subsets of the array receiver

- Does not require knowledge of array manifold

ESPRIT

- Key idea in ESPRIT is the formation of two 'identical arrays', matched arrays

- The output vectors of matched arrays x_1 and x_2 are

$$x_1(k) = V_1 s(k) + n_1(k)$$

$$x_2(k) = V_1 B s(k) + n_2(k)$$

where the diagonal matrix B has elements given by

$$z_i = \exp\left(\frac{2\pi i}{\lambda}\{d_x \sin\theta_i \sin\phi_i + d_y \cos\theta_i \sin\phi_i + d_z \phi_i\}\right)$$

- The matrix $V_1 B$ describes the translation invariance of the first array

ESPRIT

- The output of the array is

$$z(k) = \begin{bmatrix} x_1(k) \\ x_2(k) \end{bmatrix} = \begin{bmatrix} V_1(k) \\ V_1(k)B \end{bmatrix} s(k) + \begin{bmatrix} n_1(k) \\ n_2(k) \end{bmatrix}$$

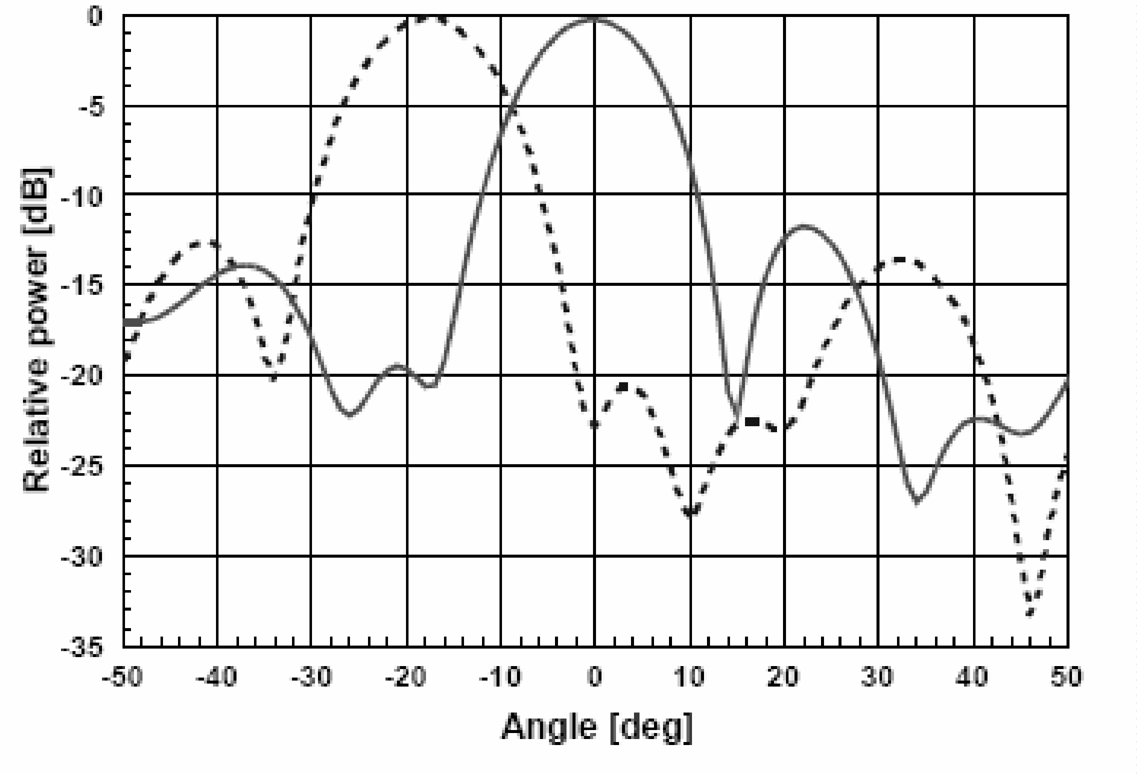
- Performing similar eigenvalue problem as with MUSIC, the signal directions can be obtained from the phases of the complex eigenvalues

- Advantage: array calibration requirements are not stringent

- Disadvantage: limited array geometry

ESPRIT

- Simulated Results using ESPRIT



SAGE

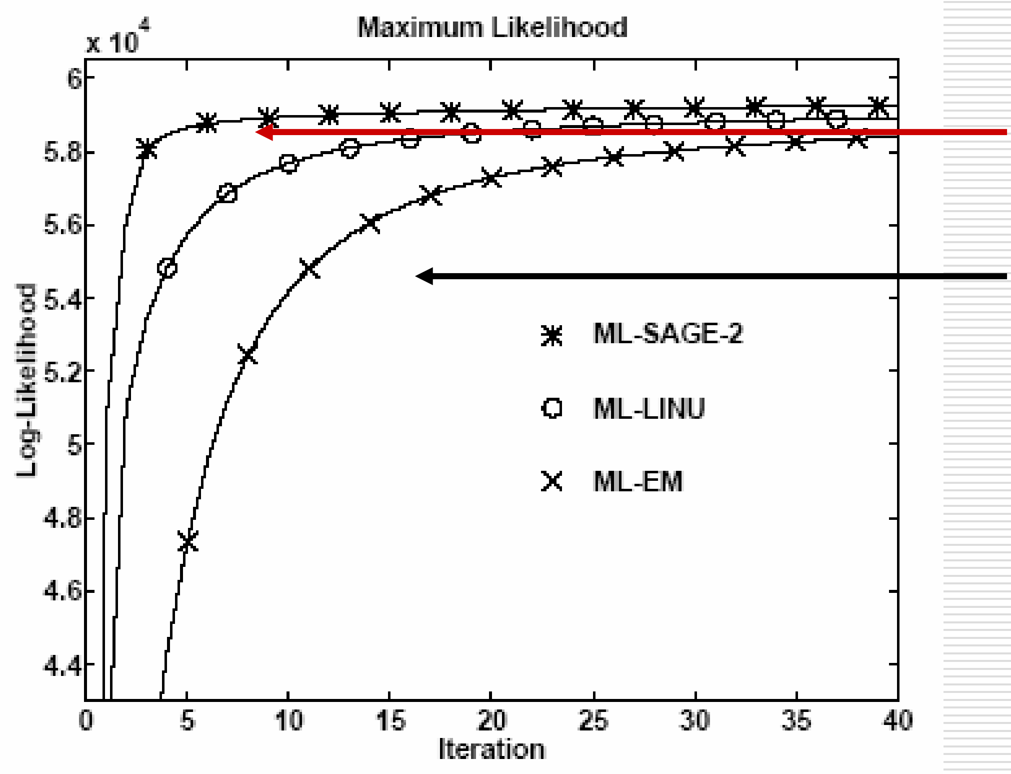
- Space-Alternating Generalized Expectation-Maximization Algorithm
- FESSLER J. A., HERO A. O. Hero. “Space-Alternating Generalized Expectation-Maximization Algorithm”, Department of Electrical Engineering and Computer Science, University of Michigan.
- Technique derived from Maximum Likelihood (ML) Method

SAGE

- The received signal is regarded as an incomplete data which may be expressed as hypothetically complete function but unobservable data
- Updates the parameters sequentially by alternating between several small hidden data spaces
- Advantage: performance is superior to the subspace based techniques especially in low SNR conditions
- Disadvantage: computationally intensive

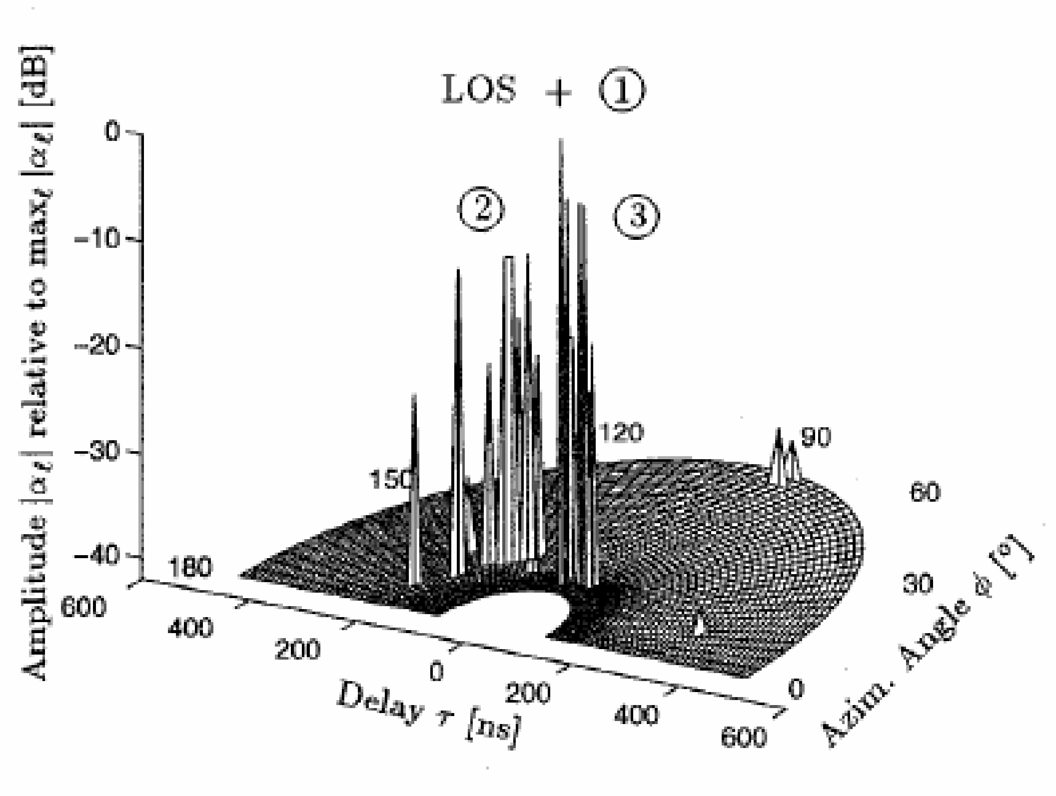
SAGE

- Simulated convergence using SAGE



SAGE

- Simulated results using SAGE



Statement of the Problem

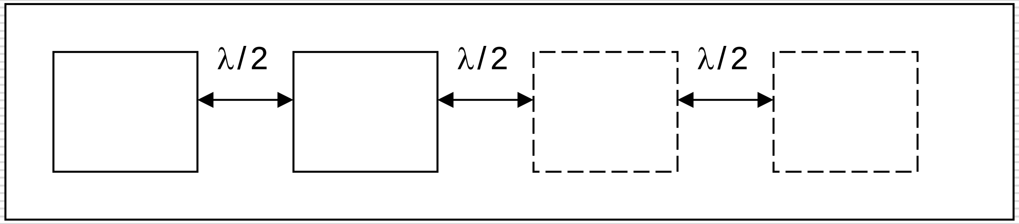
- The simulated results employing MUSIC, ESPRIT and SAGE algorithms must be experimentally verified.
- The performance of MUSIC, ESPRIT and SAGE in detecting and localizing signals should be compared.

Objectives

- To be able to successfully implement and evaluate MUSIC, ESPRIT and SAGE algorithms using empirical measurements;
- To be able to implement a physical testbed for data gathering;
- To be able to investigate the effects of varying experimental set-up parameters.

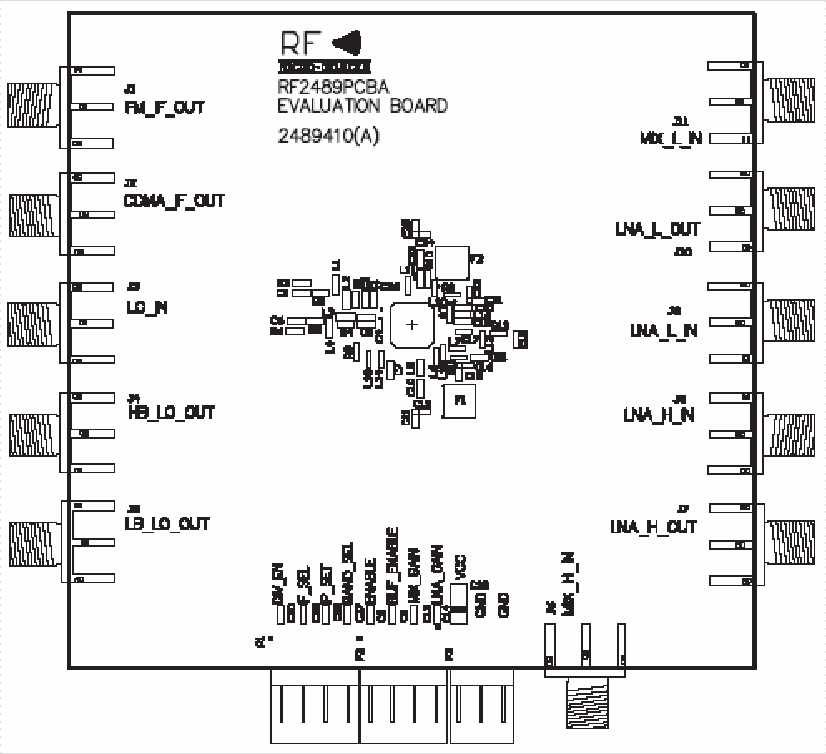
Methodology

- Design and Implementation of the antenna elements for the virtual antenna array
  - implemented using an omnidirectional monopole antenna
  - Compatible with F_c=1.9Ghz
  - Virtual antenna array



Methodology

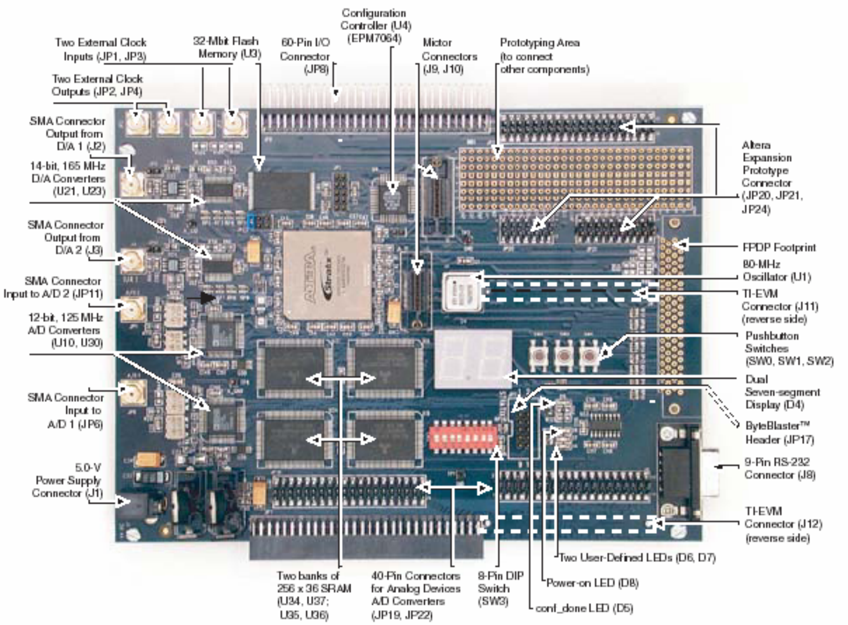
- Implementation of the analog RF front-end receiver circuitry for each antenna
  - LNA and Mixer
  - IF=110Mhz
  - RF2489



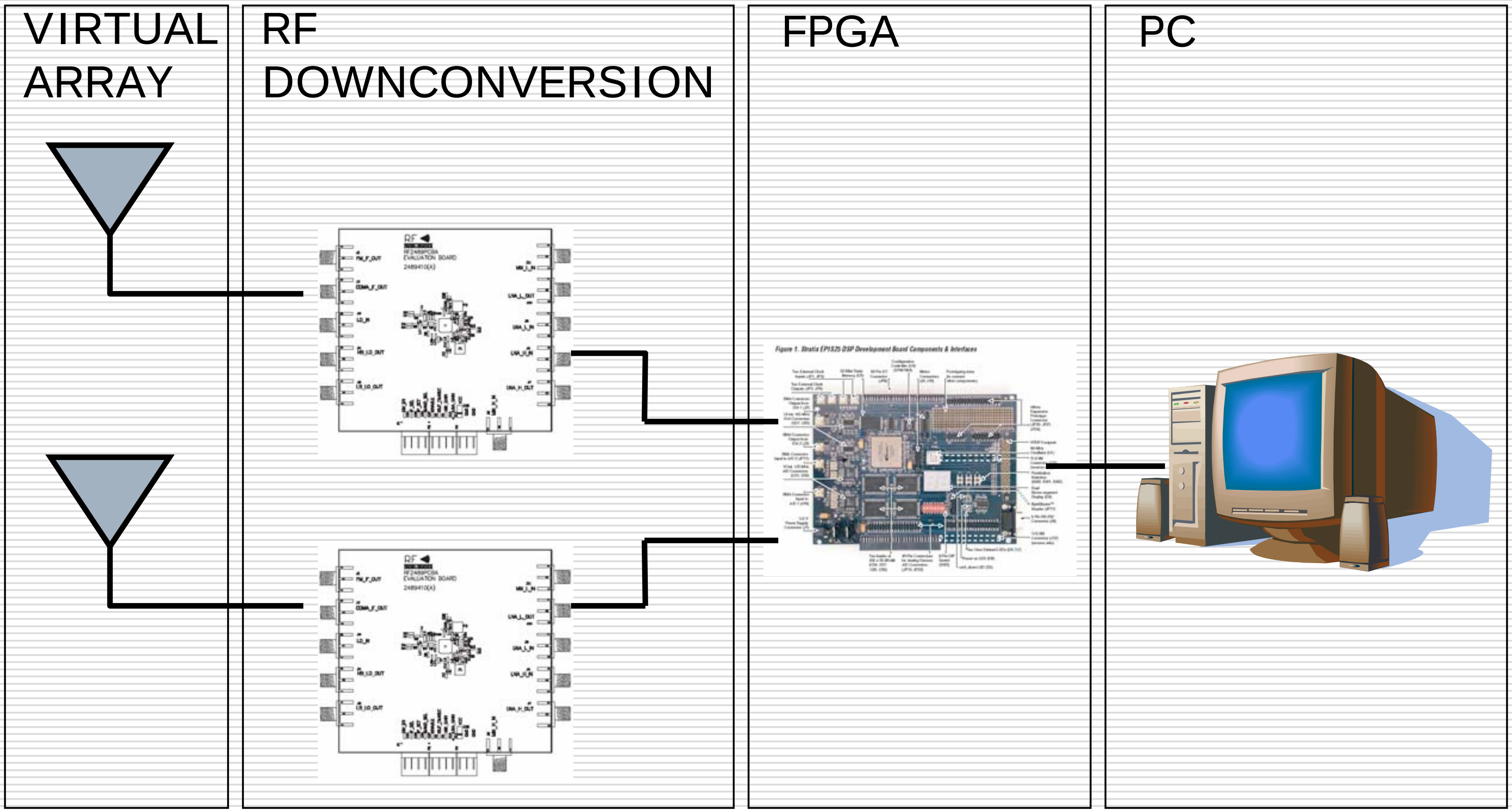
Methodology

- Configuration of the data acquisition blocks and interface to the personal computer (PC)
  - Sample data at 80MHz
  - Store data on on-board SRAM

Figure 1. Stratix EP1S25 DSP Development Board Components & Interfaces



Testbed Block Diagram



Methodology

- Testing of individual sub-systems
  - Antenna Sub-block
    - Input impedance
    - Spatial response
  - RF analog front-end receiver sub-block
    - input impedance, gain and phase response
    - Frequency response
  - IF digital sub-block
    - ADC outputs
    - Communication to PC

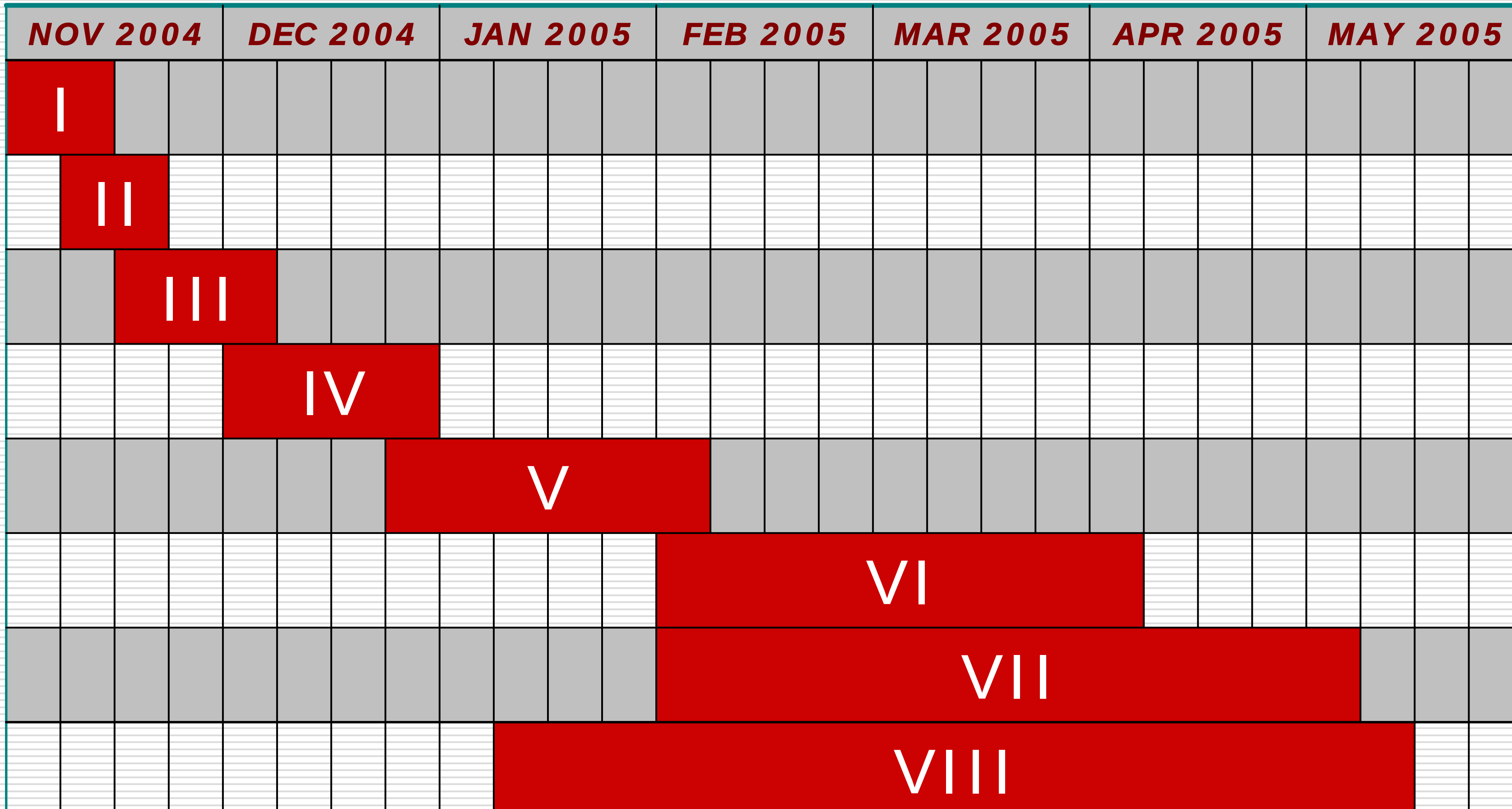
Methodology

- Data acquisition
  - Source: Vector signal generator
    - Modulation Scheme: BPSK
    - Fc=1.9Ghz
  - Emulate 4 and 8-element uniform linear array

    Parameters

    - Inter-element spacing
    - Transmitter signal power
    - Antenna array structure
    - Direction of the source
- Offline Processing using MATLAB®

Gantt Chart


NOV 2004
DEC 2004
JAN 2005
FEB 2005
MAR 2005
APR 2005
MAY 2005
I
II
III
IV
V
VI
VII
VIII

Phases

I. Design and Implementation of the antenna elements for the virtual antenna array
II. Implementation of the analog RF front-end receiver circuitry for the single antenna
III. Configuration of the data acquisition blocks and interface to the personal computer (PC)
IV. Testing of individual sub-systems
V. Testing and Calibration of the complete system
VI. Data acquisition
VII. Offline processing of empirical data using MUSIC, ESPRIT and SAGE
VIII. Documentation

THANK YOU!