A Brief History of Three Ideas in Signals : Estimation, Localization and Transmission

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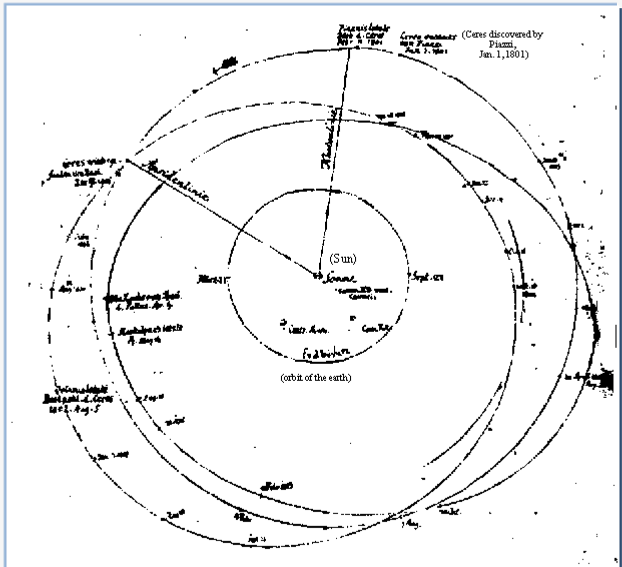
“Ten geographers who think the world is flat will tend to reinforce each other’s errors….Only a sailor can set them straight.” John Saul

Estimation of Signals in Noise

History, Prior to 1970

- Karl Gauss – Method of Least Squares
- Norbert Weiner – Covariance Model, Stationary Statistics
- Rudi Kalman – Dynamical (non – stationary) signal models (Gauss –Markov)
- Kolgomorov –

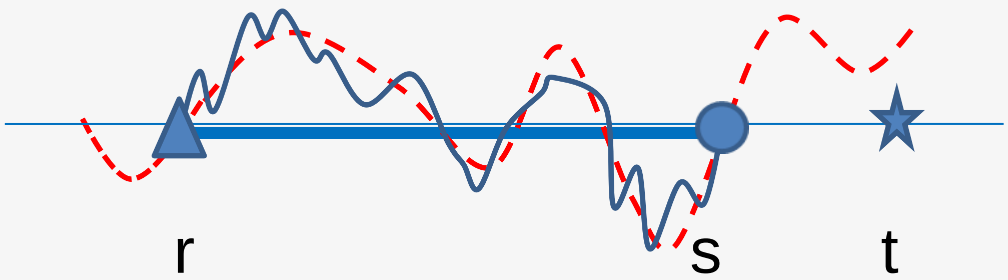
  Non-Gaussian models



Sketch of the orbits of Ceres and Pallas (nachlaß Gauß, Handb. 4). Courtesy of Universitätsbibliothek Göttingen.




Signal Extraction Problem



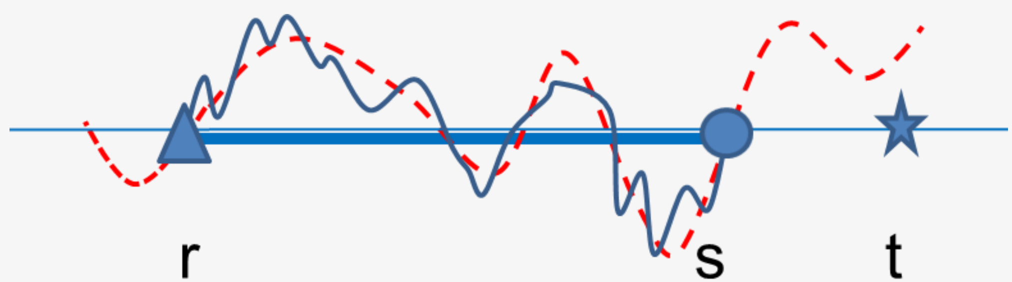
Signal corrupted by Additive White Gaussian Noise observed over the interval [r,s] where

- s current time of observation
- r start time of observations
- t time for desired estimate of signal

1970 State of the Art

- Linear (Kalman Filtering KF) for Gauss-Markov signals. Propagates Cond. Mean and Covariance.
- Non-linear filtering for Non-Gaussian signal models. Propagate conditional pdfs of signal
- Limited formulations : r is fixed, t = s, t = s + u, or = s – u

  (u is a const.)



INS Betwa Fire Control System

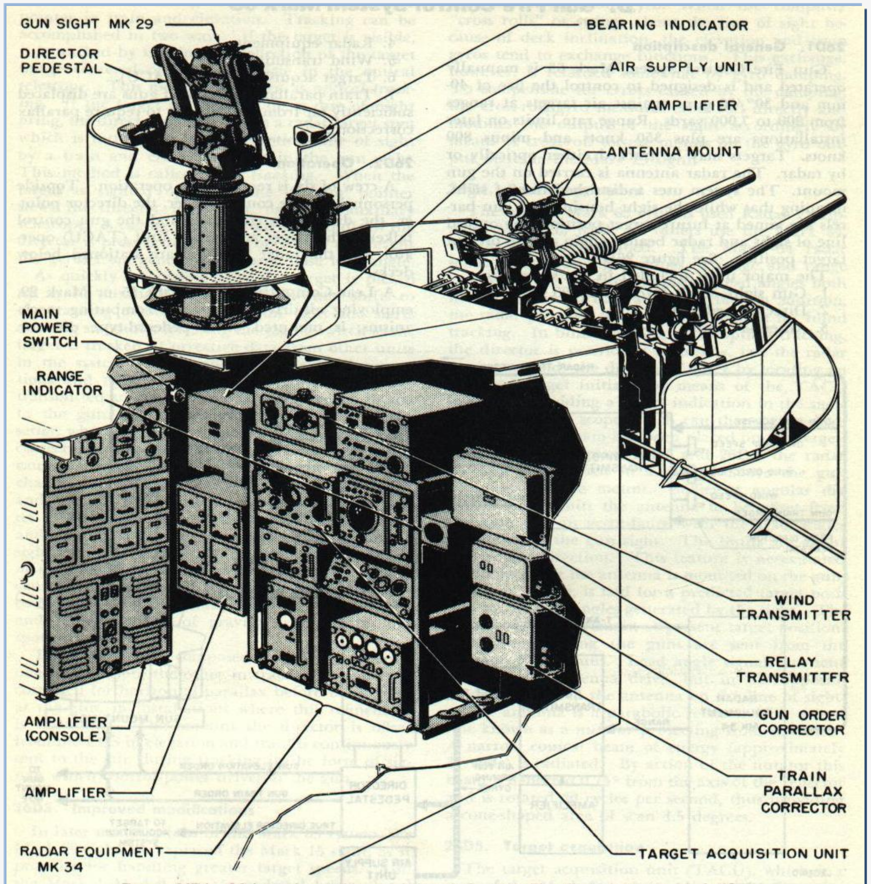
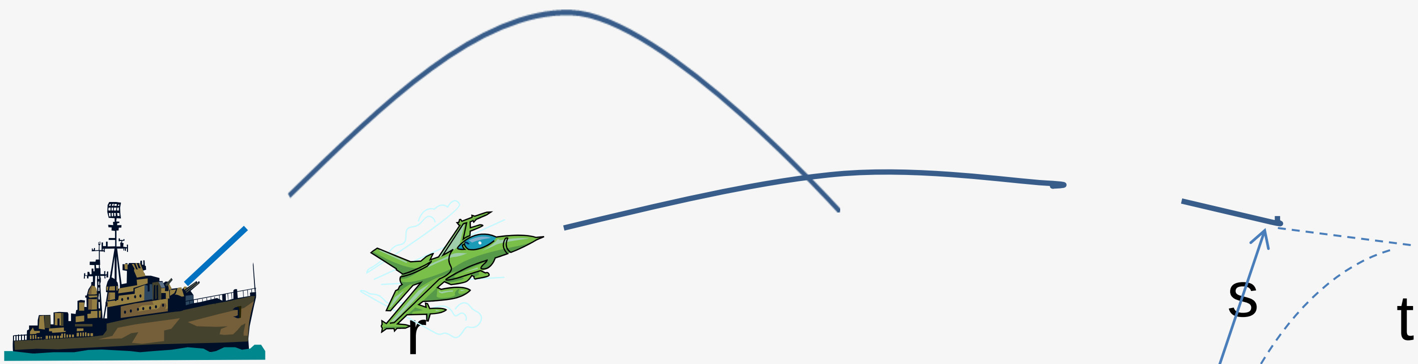
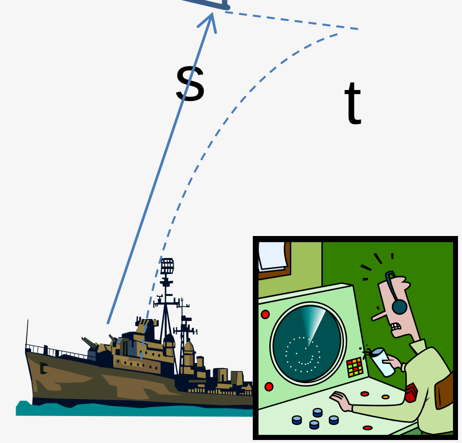


FIGURE 26D1.—Major units topside and below decks, Gun Fire Control System Mark 63.

Fire Control Problems



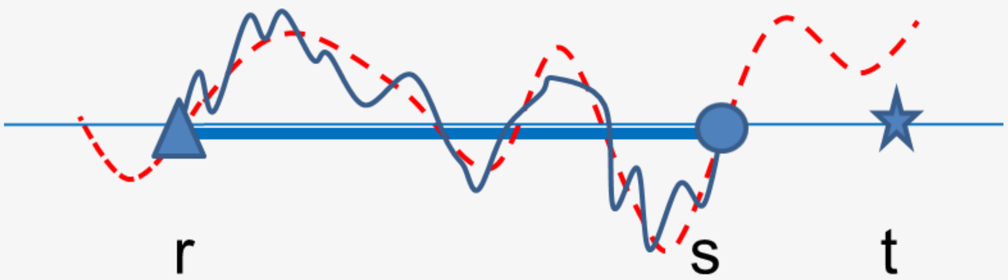


- r, s and t have more complex relationships
- Interrupted measurements
- Uncertain measurements

General Solution for Estimation

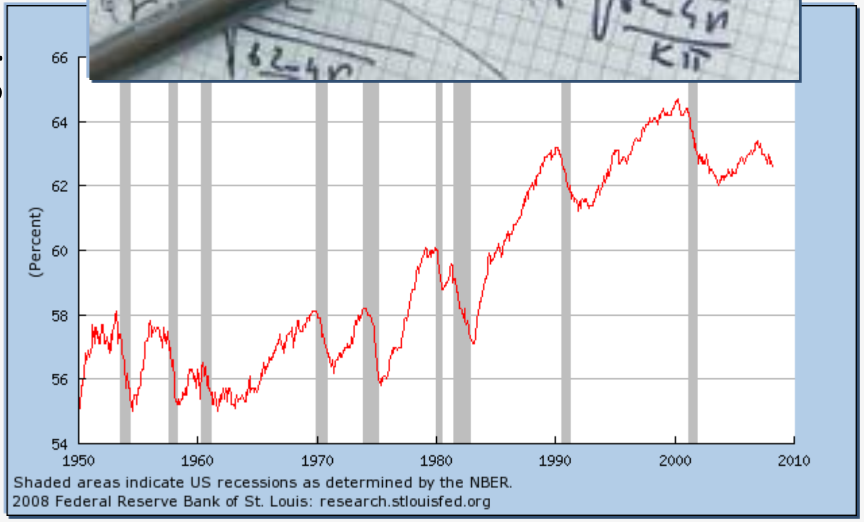
$$E_0^{a_{x_s} \vee a(Z_t)}[\Lambda_s \, h(Z_s)] = E_1^{a_{x_s} \vee a(Z_t)} h(Z_s) \, E_0^{a_{x_s} \vee a(Z_t)} \Lambda_s$$

- A solution where r, s and t could be related by a differential equation. In particular ‘r’ is also a variable. Also, Interrupted & Uncertain measurements



Applications

- Ito Calculus methods lost favor in Engg. but remain popular in financial modeling
- Flexible r, s and t useful in stock / derivative modeling



Localization – Directions of Arrivals (DOA) Problem

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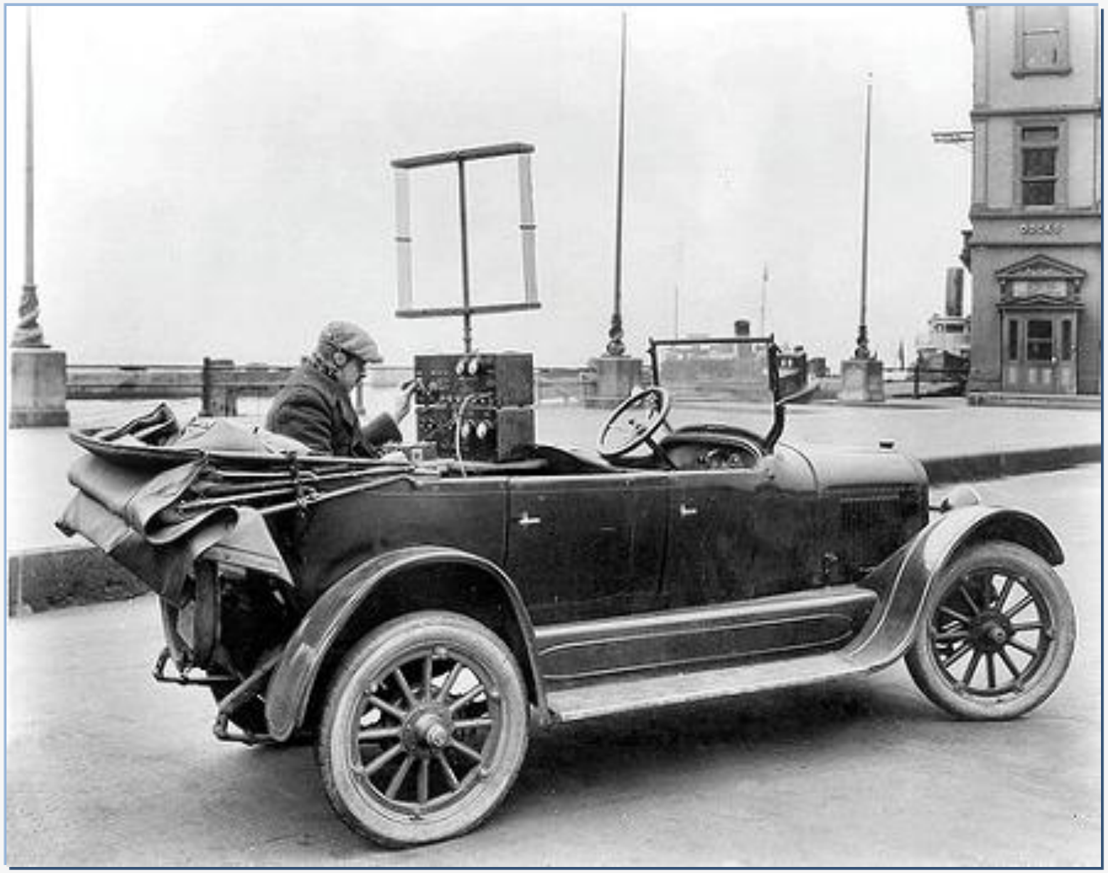
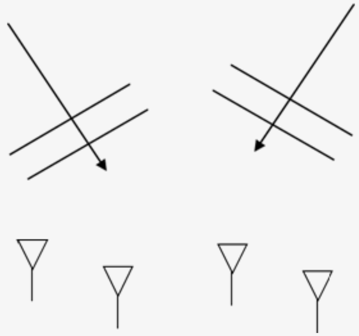
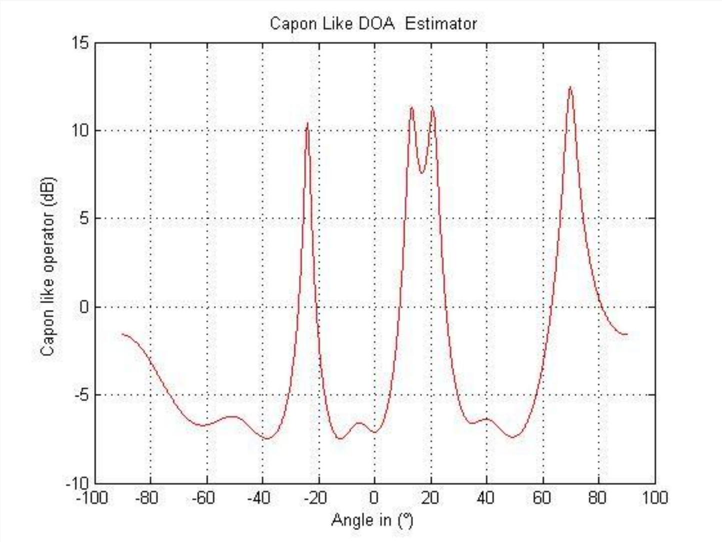
Directions-of-Arrival Estimation



Multiple Signals DOA

- Capons Method 1960s
- Burg’s Method – 1970s
- MUSIC (R Schmidt) – 1980s
- Not efficient (CR bound)





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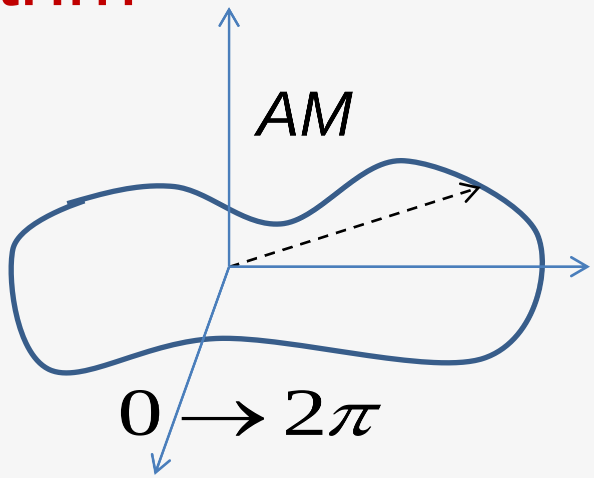
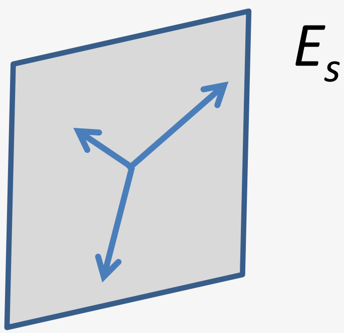
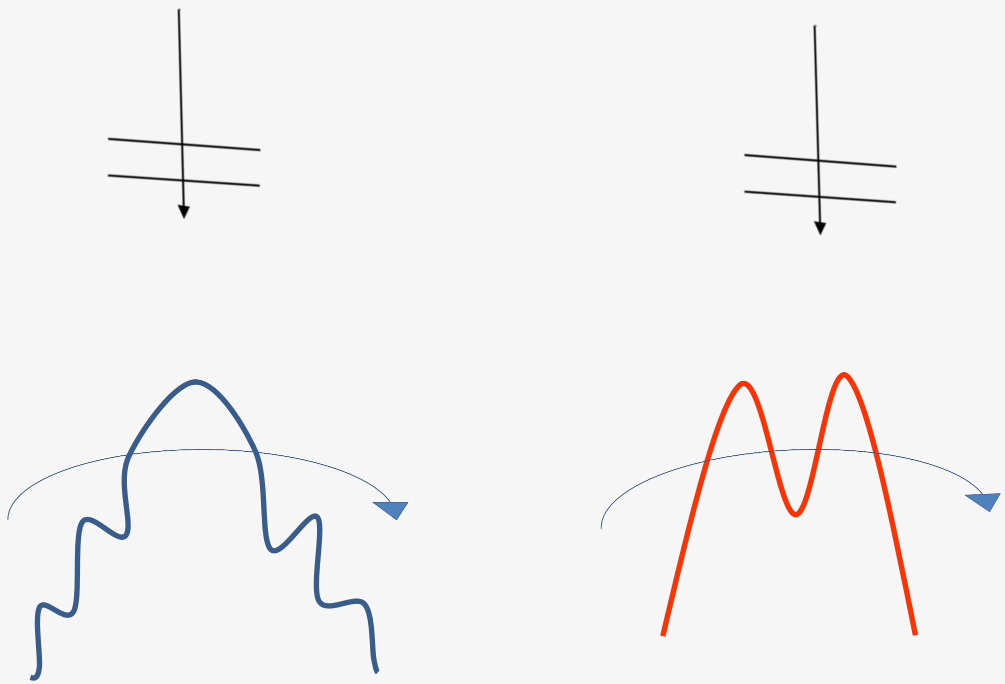
MUSIC Algorithm

- Array Manifold (*AM*) lies in C^m and is induced by a planar wave front arriving at an M element antenna array
- E_s is signal subspace induced by ‘d’ (< M) signals arriving at he array
- DOAs are intersections of E_s and *AM*



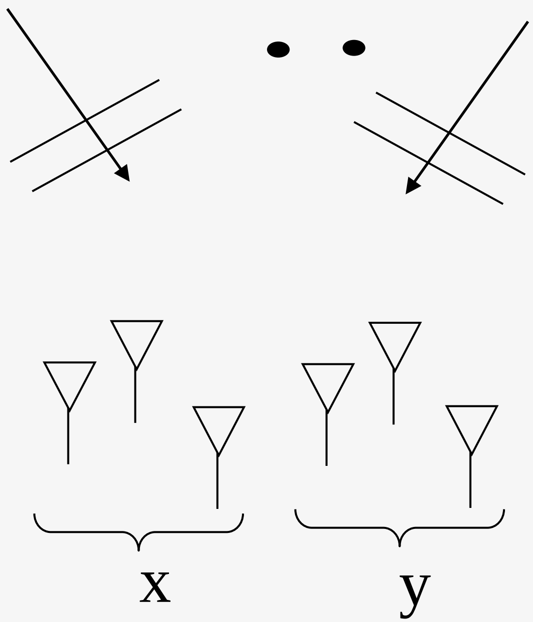


Passive Sonar DOA



Beam Scanning vs Null Scanning

ESPRIT - 1985



ϕ Diag. Matrix = DOAs

E_{xx} Signal Cov (m x m)

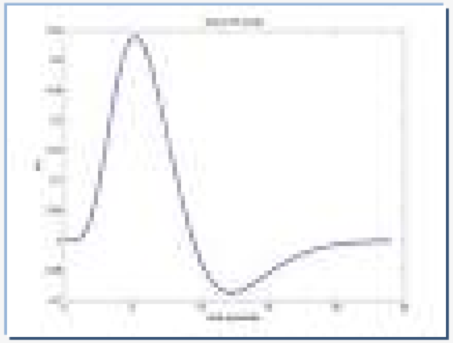
E_{xy} Signal Cross (m x m)

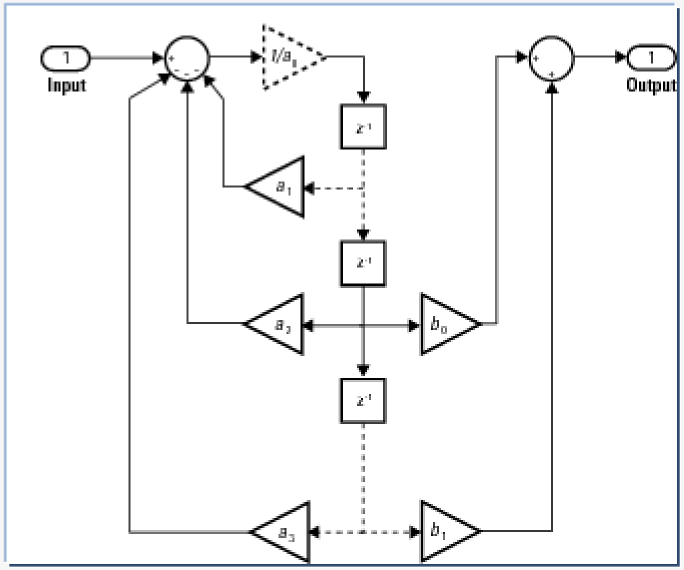
T d x d matrix

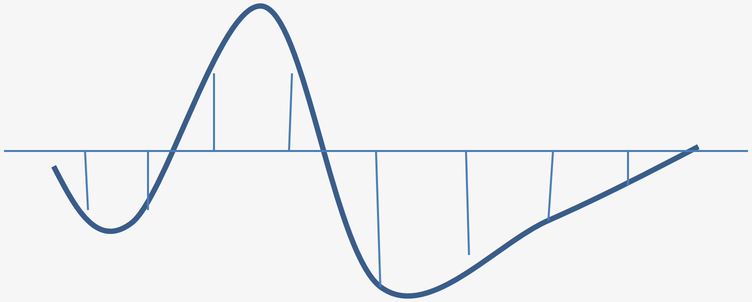
$$E_{xx}T = \phi E_{xy}T$$

System Identification

- ESPRIT can also identify modes of linear system from its Impulse Response

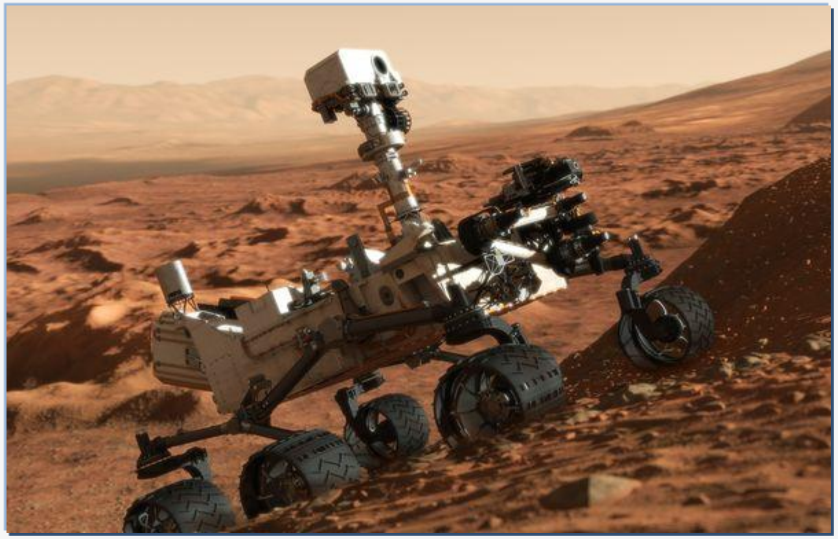






ESPRIT Applications

- > 900 IEEE xplore papers, > 60 PhDs
- Radio DF
- Acoustic DF
- System ID
- MIMO Wireless Channel ID
- Spectrum Analysis



Curiosity – MARS Explorer

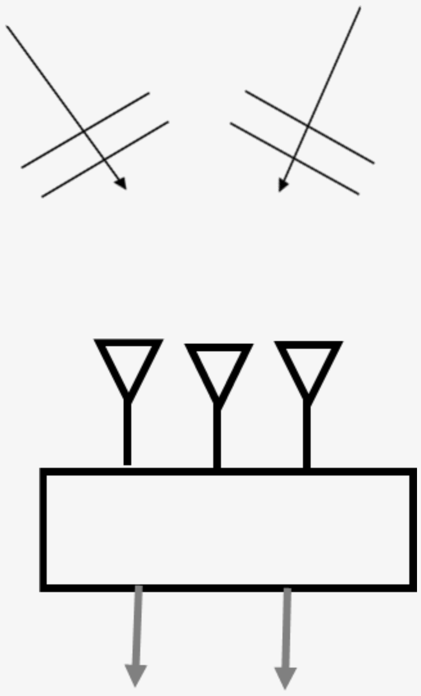
Transmission : MIMO Spatial Multiplexing

Signal Copy Problem

Blind Methods

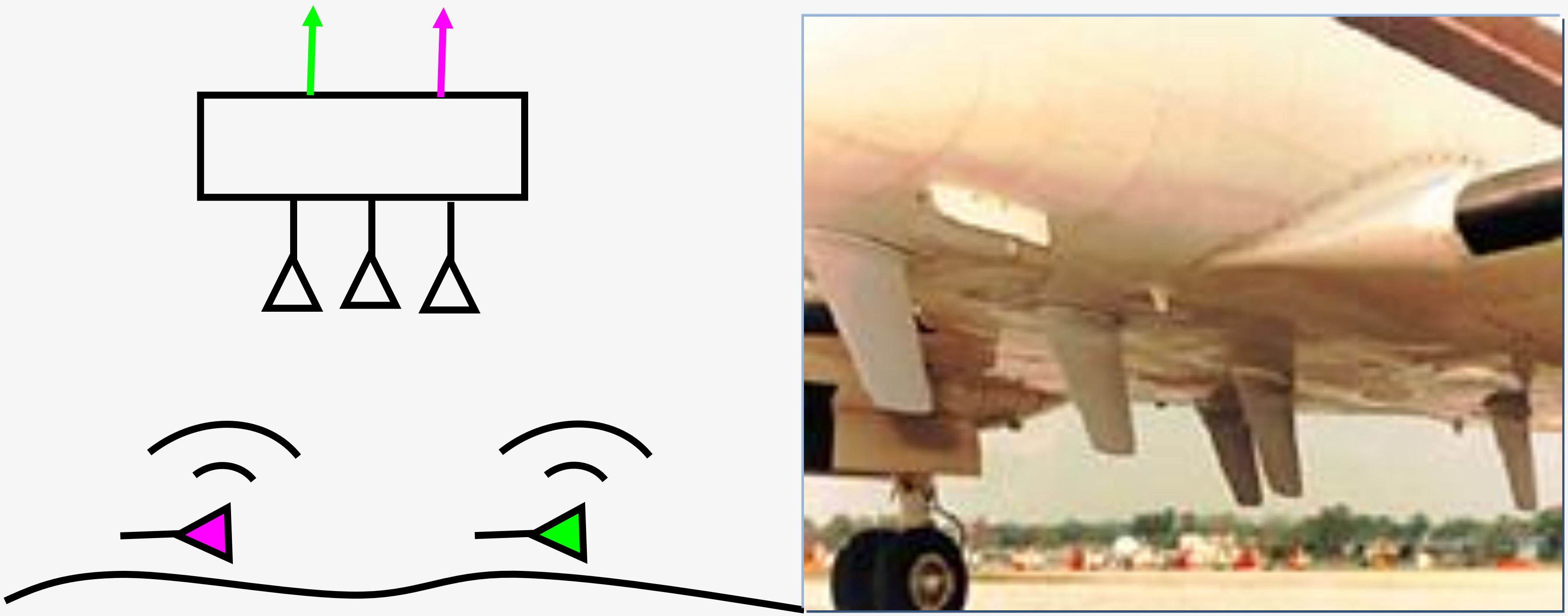
- Bussgang Methods
- Finite Alphabet
- Constant Modulus
- MT-MORE

- Temporal side Information
- Spatial side information



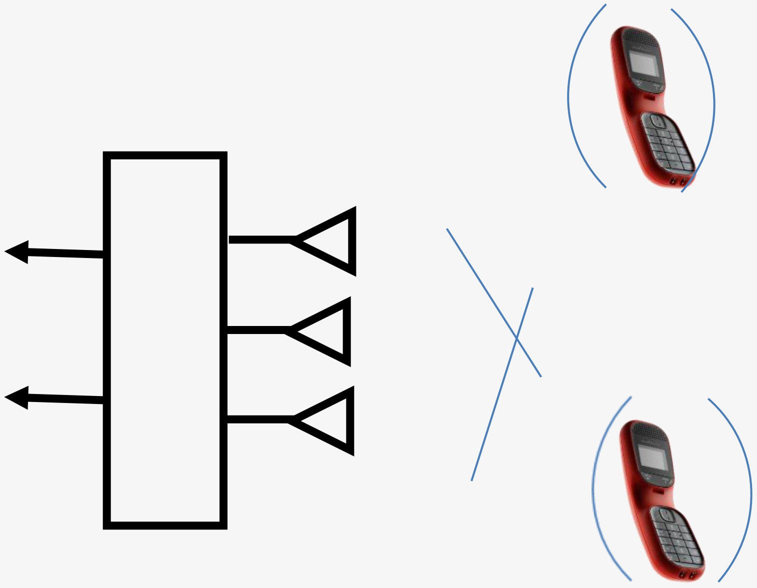
Signal Copy Problem

DARPA Signal Copy Project

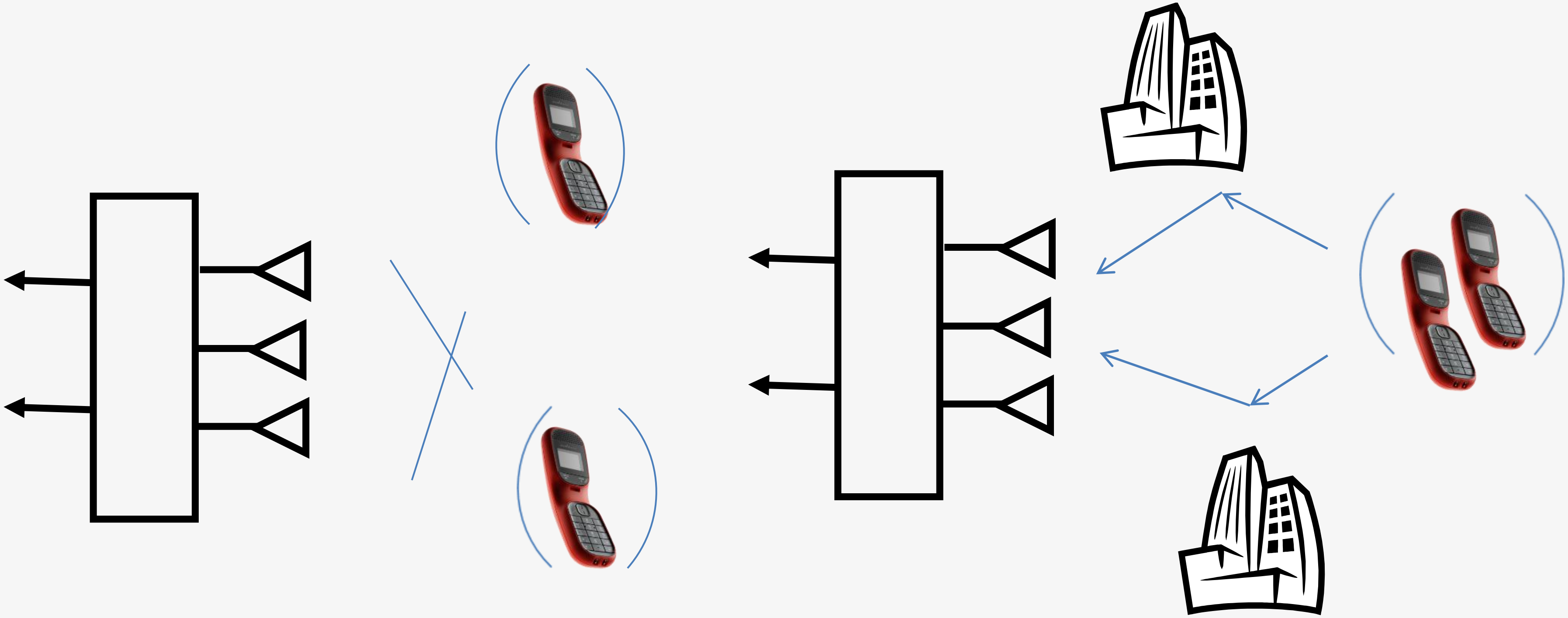


Co-channel Sources

SU Experiments 1992



SU Experiments 1992



MIMO Spatial Multiplexing - 1992

US Patent '599
Filed 1992, Issued 1994

$$Throughput \approx \log\det\left(I + \frac{\rho}{M} HH^*\right)$$

$$\approx \; Min\,(N_T\,,N_R\,)$$

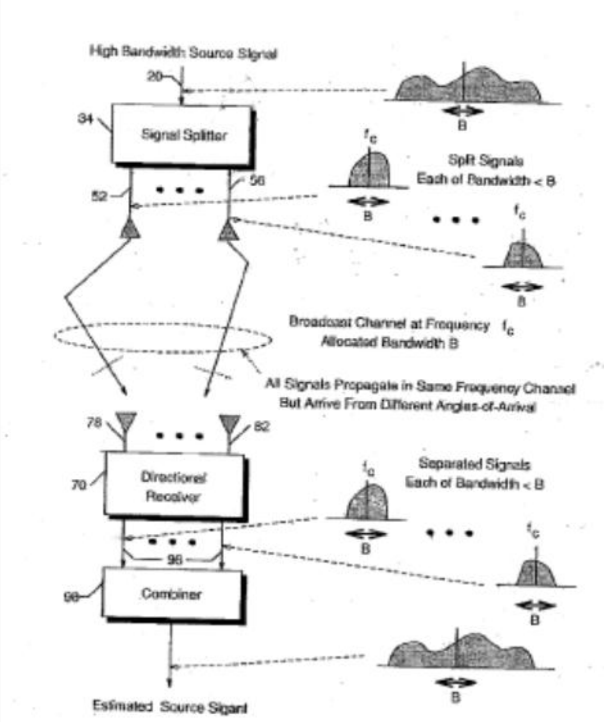
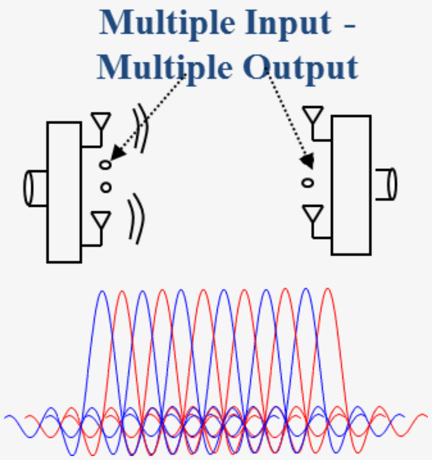


FIG. 1: Signal Flowchart of the DTDR Invention

Iospan Wireless -1998

- OFDMA was a good modulation scheme for MIMO
- But needed some "fixes" for improving signal and inference diversity
- Iospan -> Intel -> 4G



MIMO Today

- 14,000+ Pubs (Thompson)
- 12,000+ Patents (USPTO)
- 1000+ PhD Theses (ad hoc)

- WiFi 11n, 11ac
- 3GPP LTE
- WiMAX
- 3GPP HSPA+

Some Lessons & Observations

A Lesson

Disseminate/ Publish

- Reviews can refine or correct your ideas, recruit collaborators and find applications
- Do not wait for full solutions or complete results
- Great ideas are often simple or obvious (at least to you), but that should not deter publication

A Lesson

To bring an innovation or invention to practical use requires persistence in face of failures and sometimes blindness to criticism

An Observation

Inspiration often come observing nature or from experiments

- The generalized estimation problem came from my curiosity about Navy fire control systems
- Localization formulation came from my sonar development experience
- MIMO spatial multiplexing came from Stanford signal copy experiments

An Observation

Good ideas can sometimes be rejected as totally ridiculous (but later miraculously become completely obvious)

- – MIMO/SM
- – Counter factual – ESPRIT

An Observation

Breakthroughs often comes from holding the problem in ones mind for extended periods

- ESPRIT
- MIMO-OFDM

Thank you