# Spatio-Temporal Equalization for Wireless Communications

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# Overview

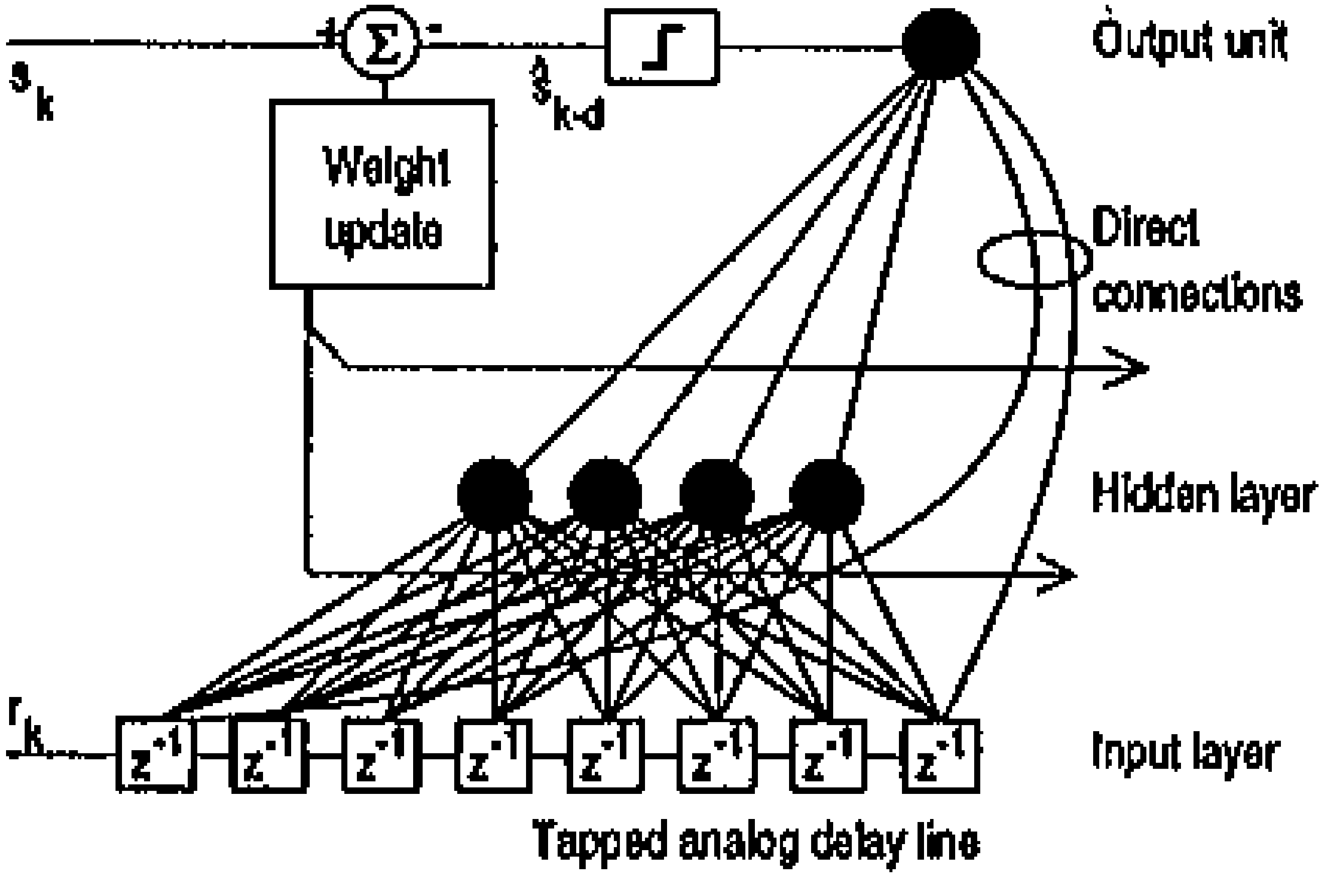
- Enhance mobile communications
  - adaptive signal processing
  - low-power, compact implementation
- Temporal dispersion correction
  - linear and non-linear equalization
- Spatial beamforming with antenna arrays
  - detect directions of arrival
  - combine paths to improve signal to noise

# Temporal Spread

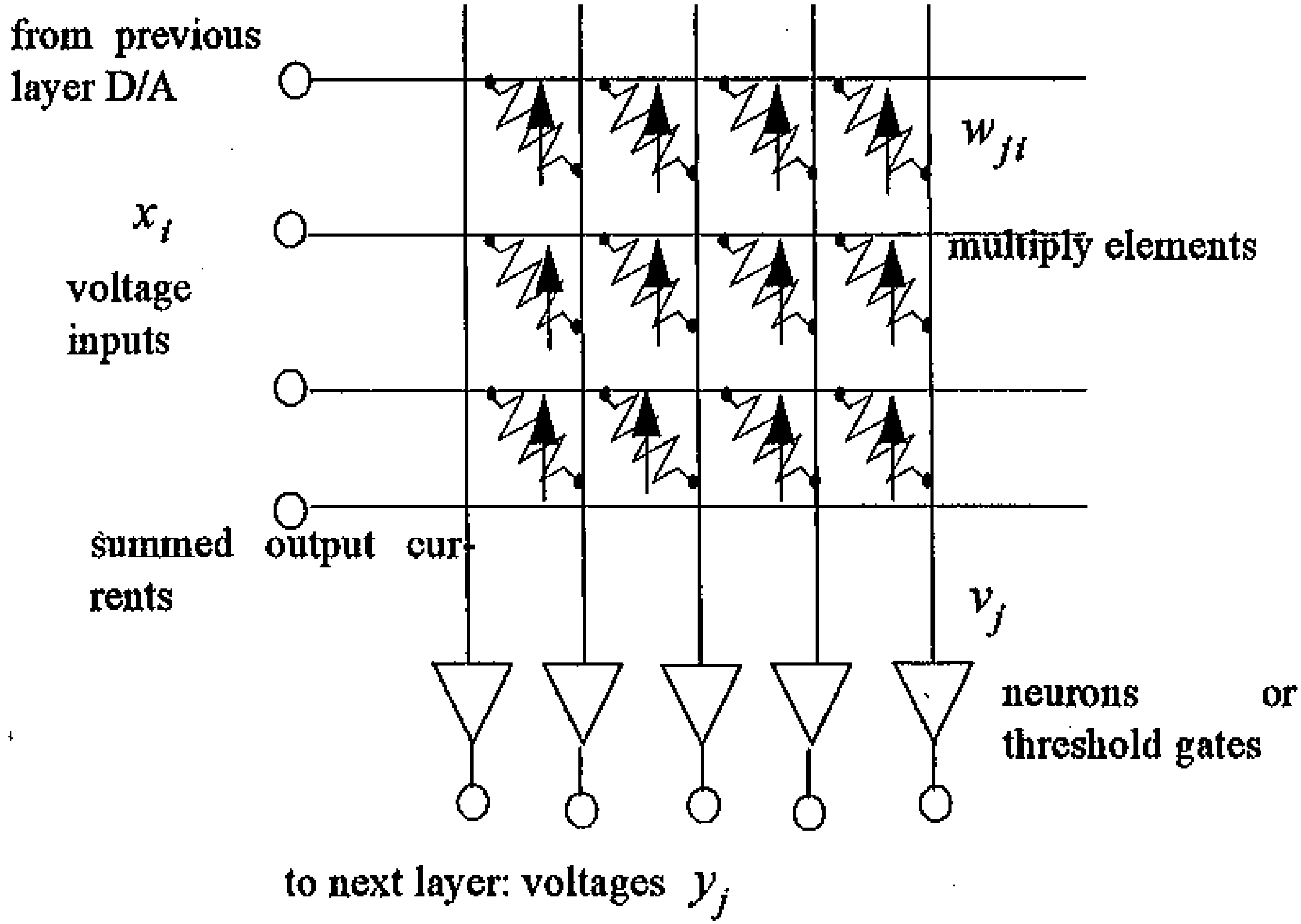
- Receive r from signal s, memory  m=p+q
  - $r_k = h_k s_0 + \sum_{j \neq k, j=-p}^{q} h_j s_{(k-j)} + n_k$  h (imp. resp.), n(oise)
- Corrected by linear equalization
  - $\hat{s}_{k-d} = W_k^T \bullet \{r_k\}$  (1 neuron network)
- If repeaters, need non-linearity, f(Wr)
- Adaptive adjustment of weight vector

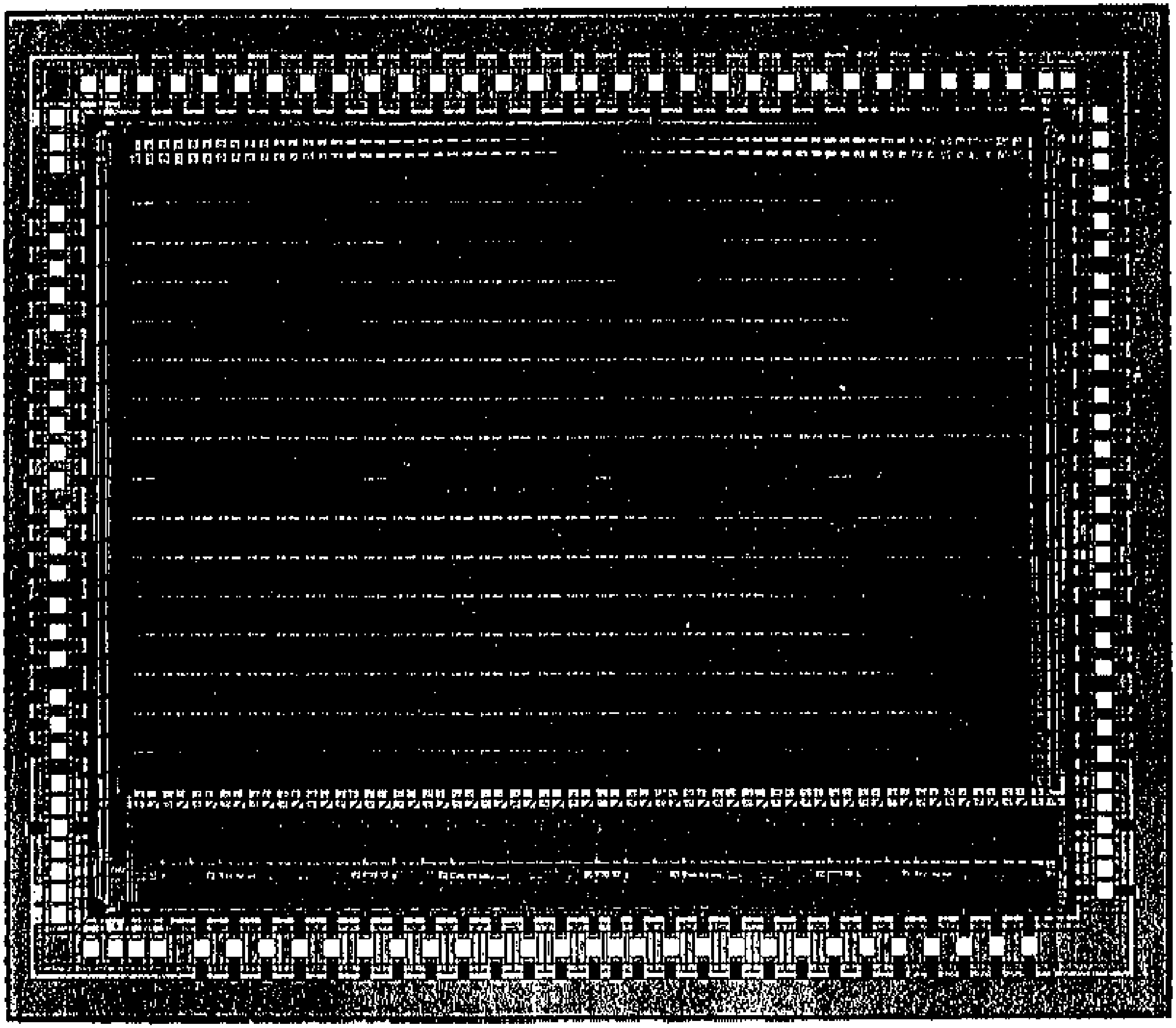
$$W_k = \{w_0, w_1, \ldots, w_{m-1}\}_k$$

# Neural Network Equalizer



# Analog Signal Processor





# Learning Chip Computational Function

Current summation

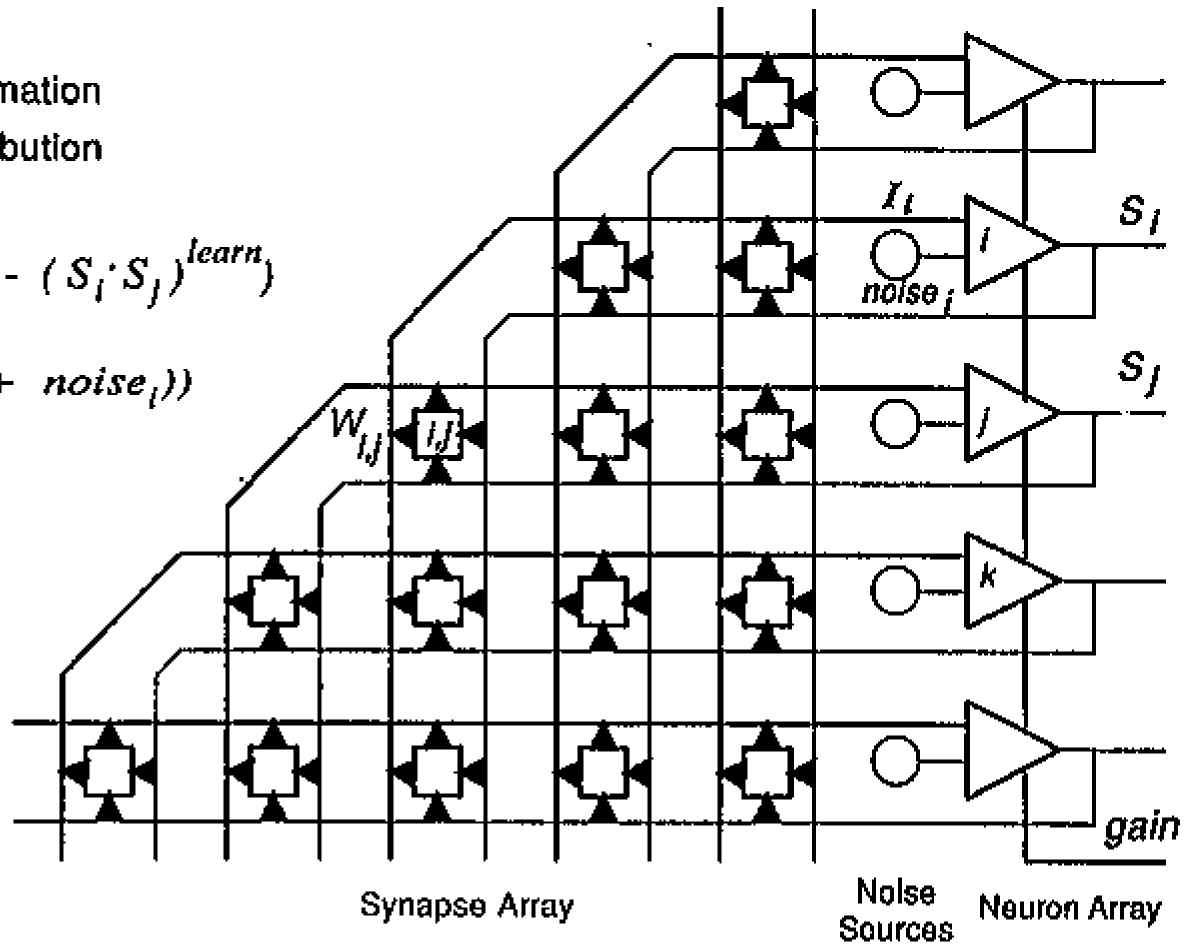
Voltage distribution

$$\Delta W_{ij} = sgn((S_i \cdot S_j)^{teach} - (S_i \cdot S_j)^{learn})$$

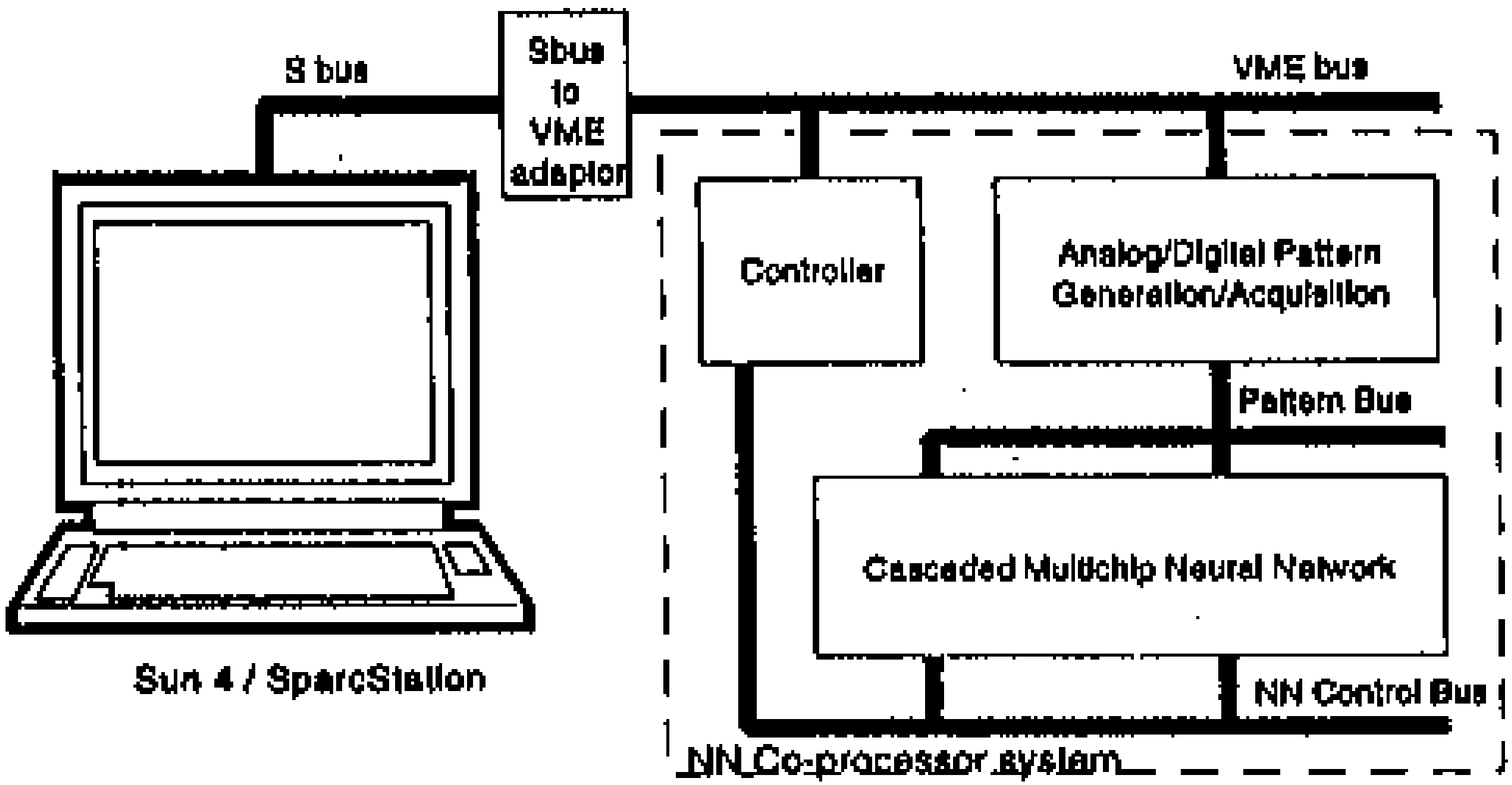
$$S_i = f(gain \cdot (netin_i + noise_i))$$

$$I_{ij} = W_{ij} \; S_j$$

$$I_i = \sum_j W_{ij} \; S_j$$

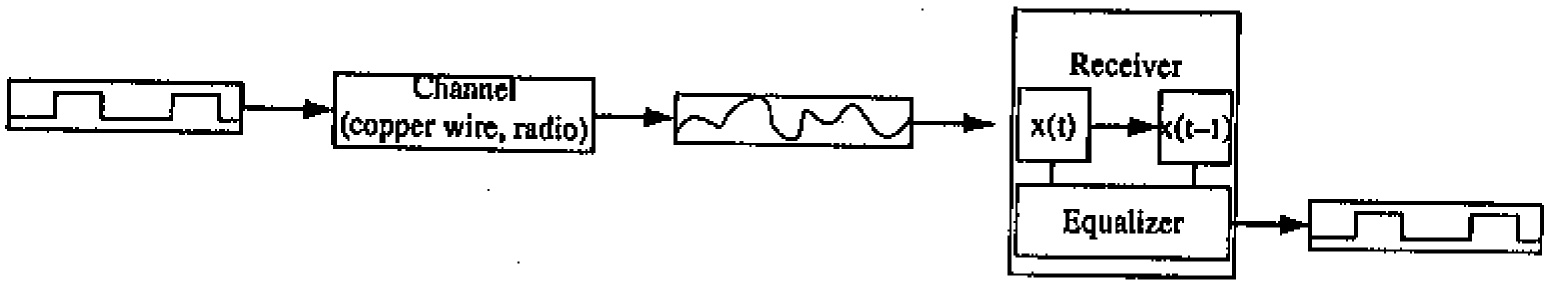


# Co-Processor Block Diagram

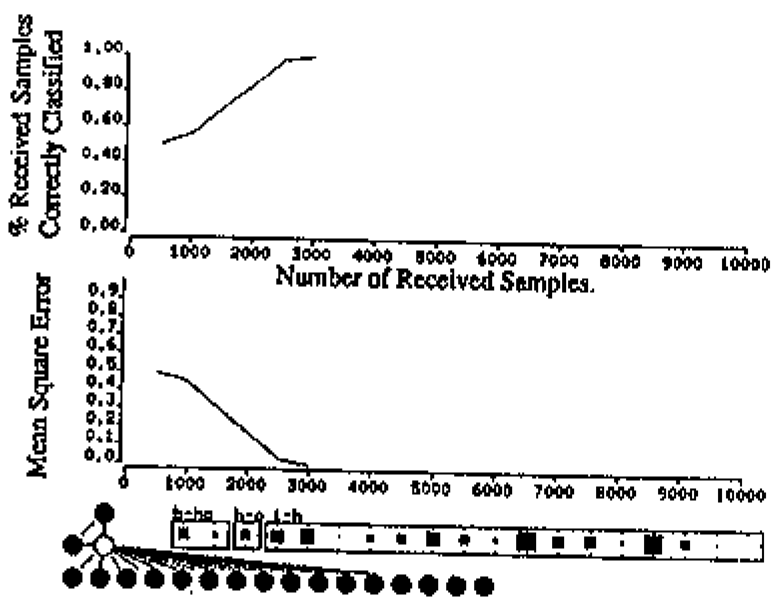


# Neural Network Equalization

## Equalization



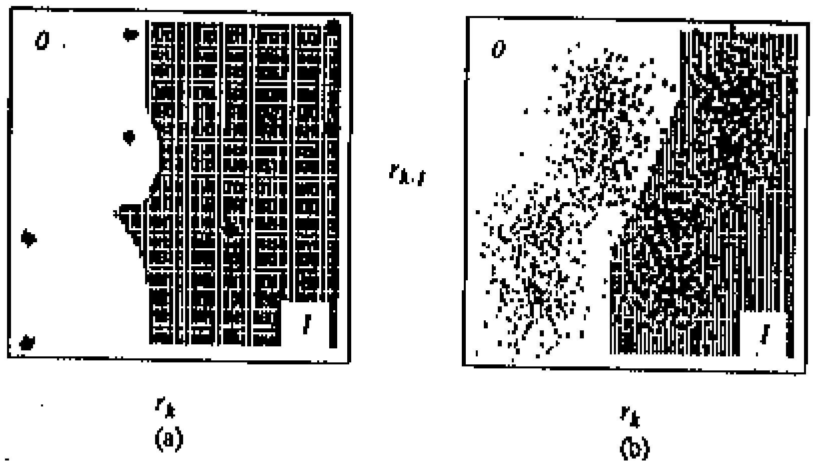

## Neural Hardware



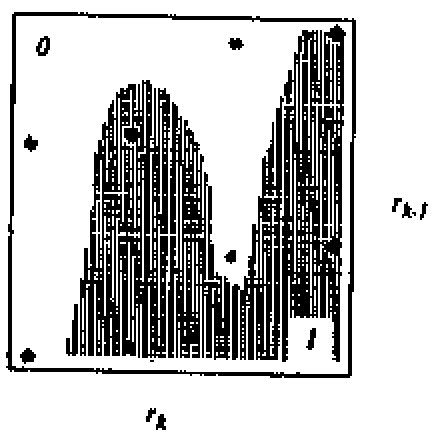

| Processing Speed (samples/second) | |
|---|---|
| Current Test Platform | 10,000 |
| Limit of Current Chip | 100,000 |
| Chip Dedicated to EQ | 1,000,000 |

Analog neural network uses 20 times less power than similar speed digital.

# *Equalization as a classification problem*




Decision boundaries drawn by the chip for the channel $H_{mp}$
under different SNRs. (a) 20 dB and (b) 8 dB

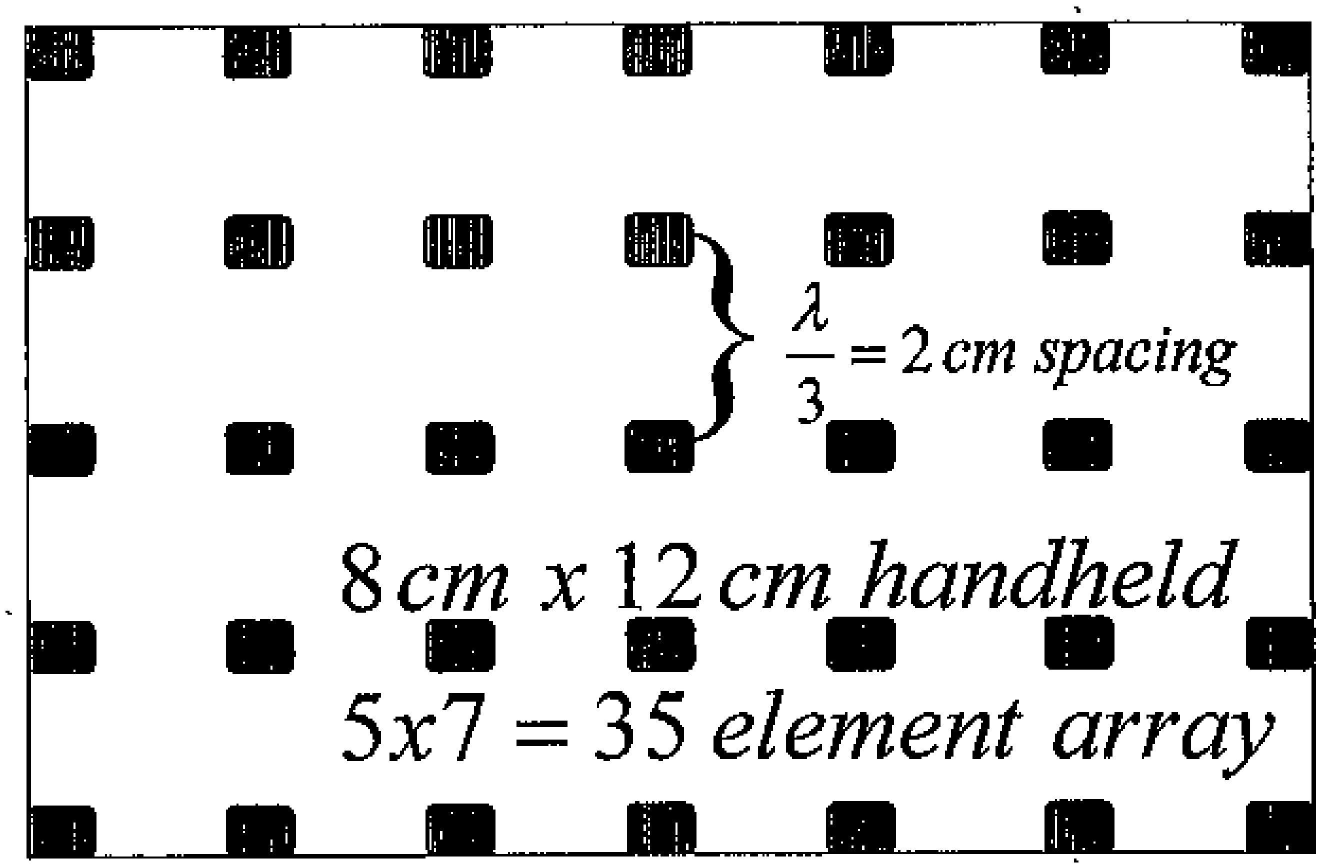



Decision boundary
for the channel $H_{nmp}$
SNR = 20 dB

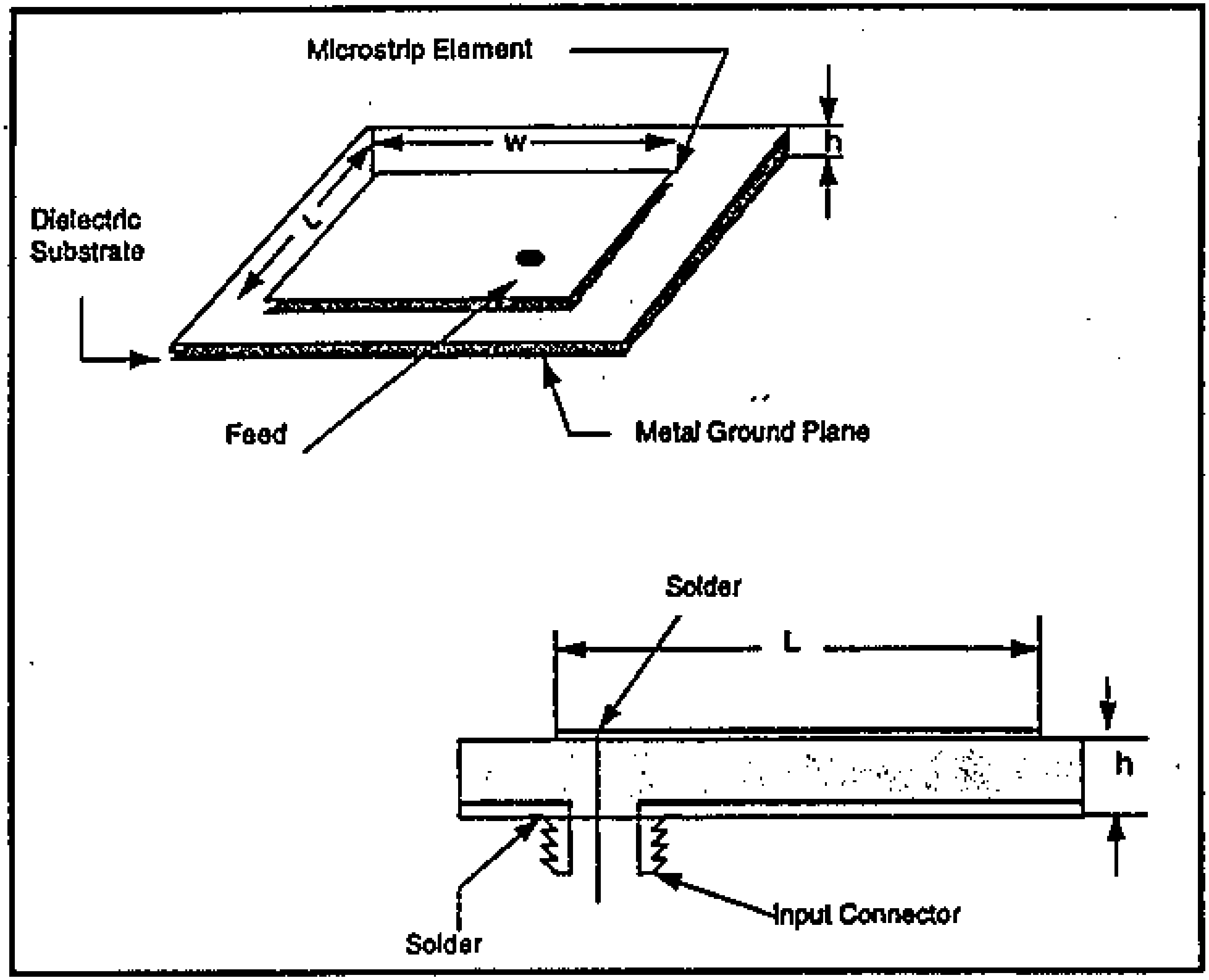
# Adaptive Antenna Arrays

- Reduce interference from other users
  - increase number of users per cell
- Array factor increase beam selectivity
  - can steer peaks and nulls with magnitude and phase in reception and transmission
- Adaptive steering maximizes signal
  - can train neural net to locate signal peaks
  - low power, compact processing is essential

# Array for 5 GHz Terminal



# Microstrip Patch Antenna




Microstrip Antenna Design

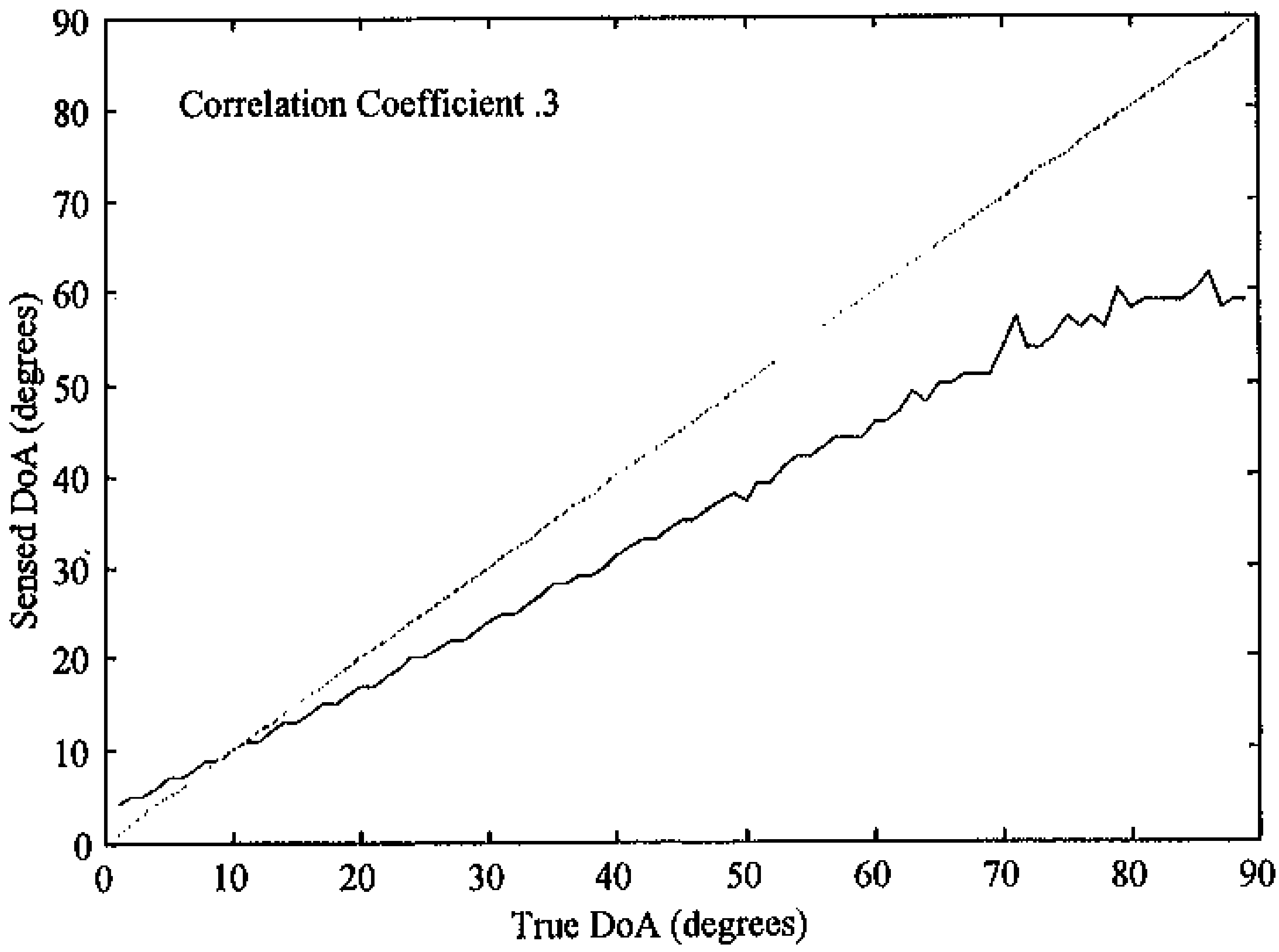
# Beam Direction Estimate

- Compare radial basis function neural network with MUSIC algorithm
- Evaluate 1-dimensional 6 element array and 2-dimensional 35 element array
- Use noisy correlated multipath signals separated by 10 to 90 degrees

# MUSIC Algorithm

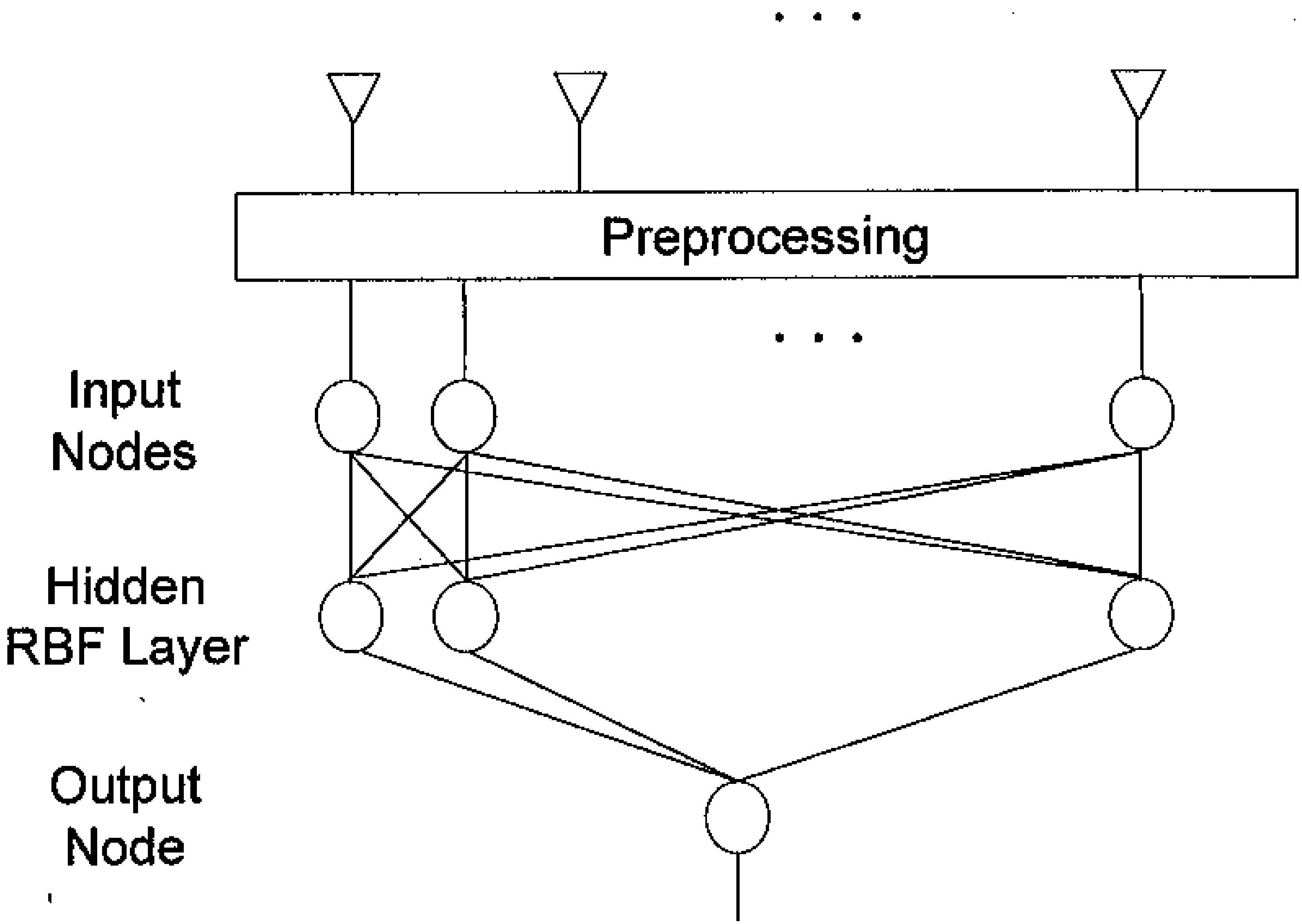
- Multiple Signal Classification (MUSIC) algorithm finds singular values of signal correlation matrix
- Can detect direction well if there are no cochannel signals (multipath)
- Otherwise does weighted interpolation between correlated signal directions and doesn’t find strongest source

• Music algorithm with one correlated source at 10 deg.

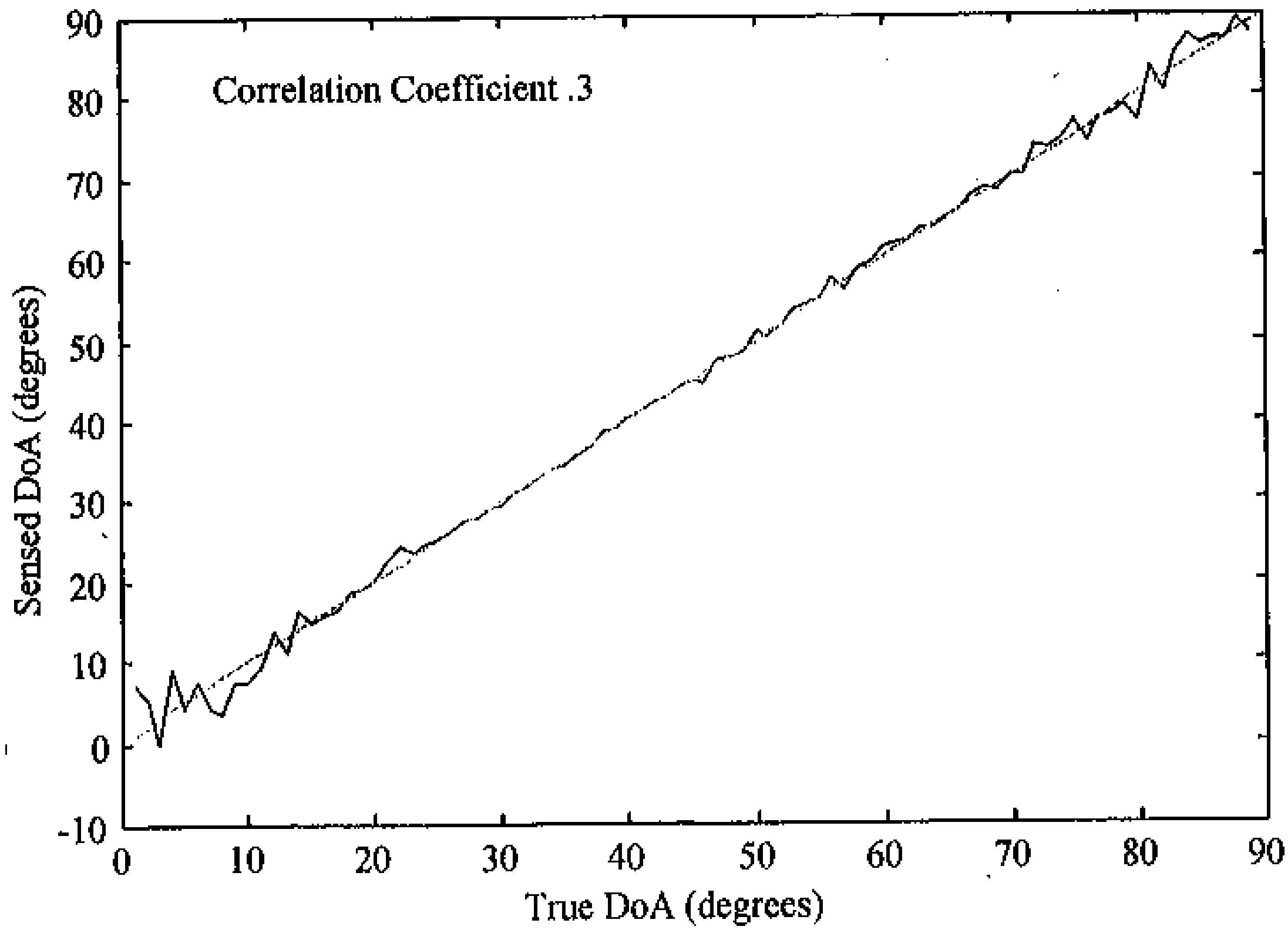


# Radial Basis Function Neural Network

- Inputs re off-diagonal correlation matrix elements (Re and Im signal components)
- Train local, radial, non-linear, basis (gaussian) middle layer with LMS by generalized inverse
- Linear output layer
- Tracks strong beam direction accurately in presence of correlated multipath signal


Preprocessing
Input
Nodes
Hidden
RBF Layer
Output
Node

• Neural network results with one correlated source at 10 deg.



# Conclusions

- Neural network training to find peak signal outperforms MUSIC algorithm in the presence of multipath signals
- Neural net training can perform temporal equalization in low-power hardware
- Combine spatial and temporal processing
- Low power hardware is feasible