Evolvable Electronic Systems

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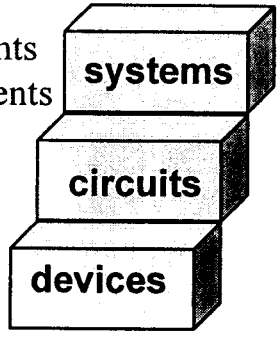
Why "genetically engineered" electronics, evolvable hardware, evolvable systems

Evolution = Optimization

Optimization at design phase- before mission -

Example:
- Evolve very small components
- Evolve multi-functional/reconfigurable components
- Evolve robust/fault-tolerant/self-healing components
- Evolve optimal designs at system level



Optimization during mission: (optimal) adaptation to new situations,changes in requirements

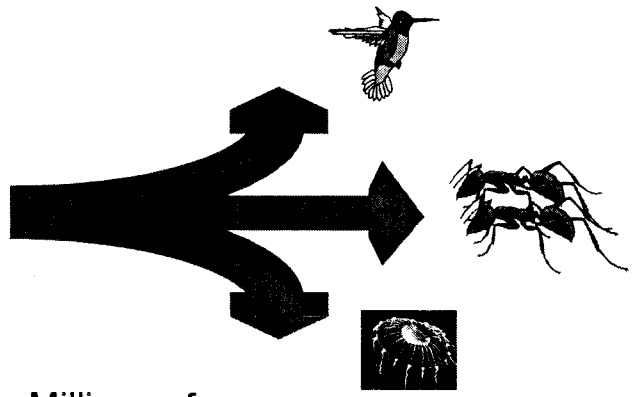
Example
- Evolve new functions, unforeseen at launch
- Evolve for in-situ adaptation
- Evolve to self-heal

Add evolvability to increase survivability
- adaptation to environments
- self-healing, self-repair

Achieve high autonomy on-board spacecraft
- **Maintain functionality under changes in operating conditions**
- **Provide new functions, not anticipated on ground**

Evolution in nature and in artificial systems

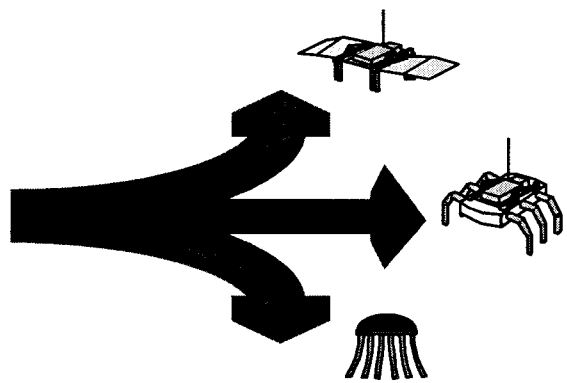
Evolution in nature has lead to species highly adapted to their environment - *adaptation ensured survival.*



Millions of years

The most fitted individuals survive becoming parents; children inherit parents characteristics, with some variations, may perform better, increasing the level of adaptation

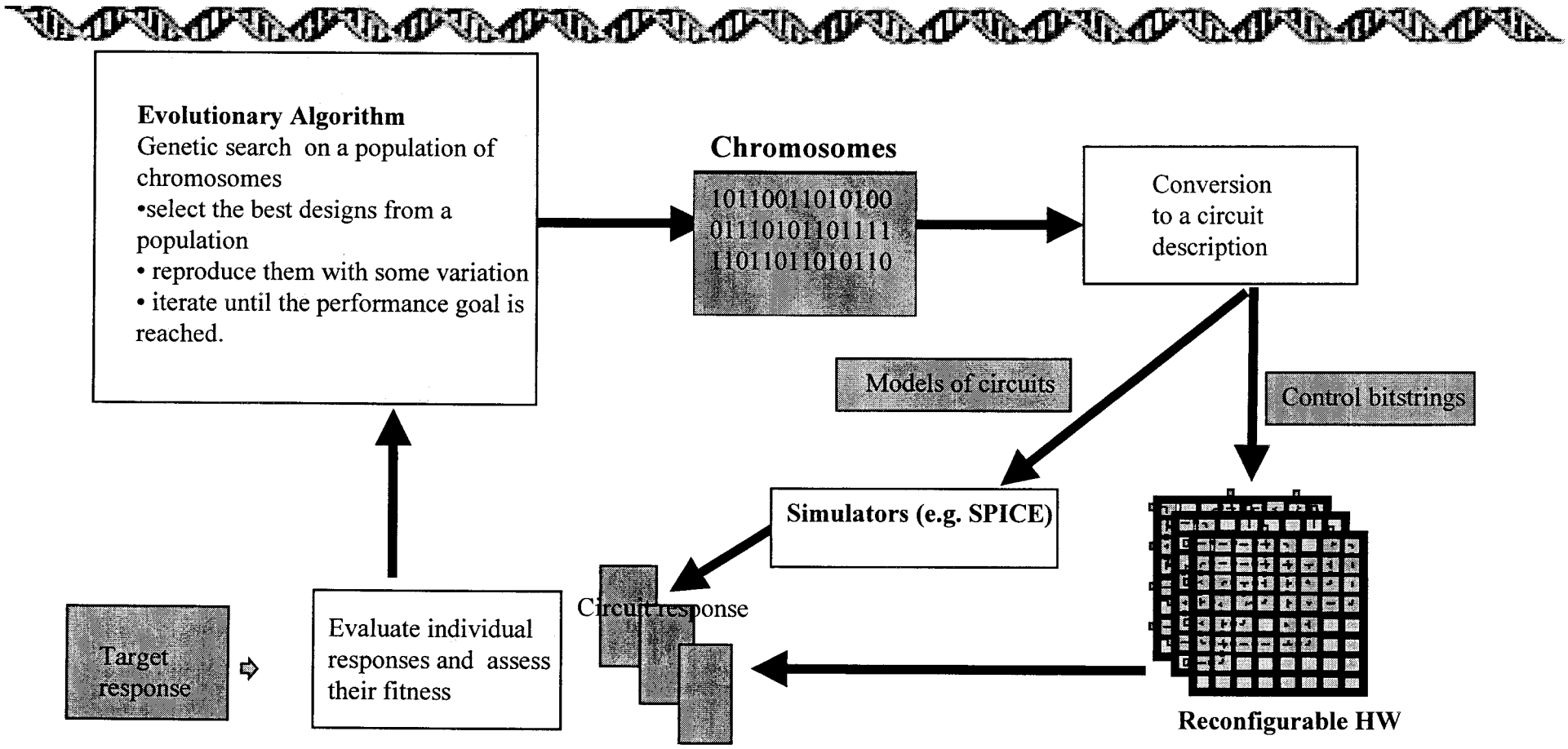
The same evolutionary principles can be applied to machines



Potential designs and implementations compete; the best ones are slightly modified to search for even more suitable solutions

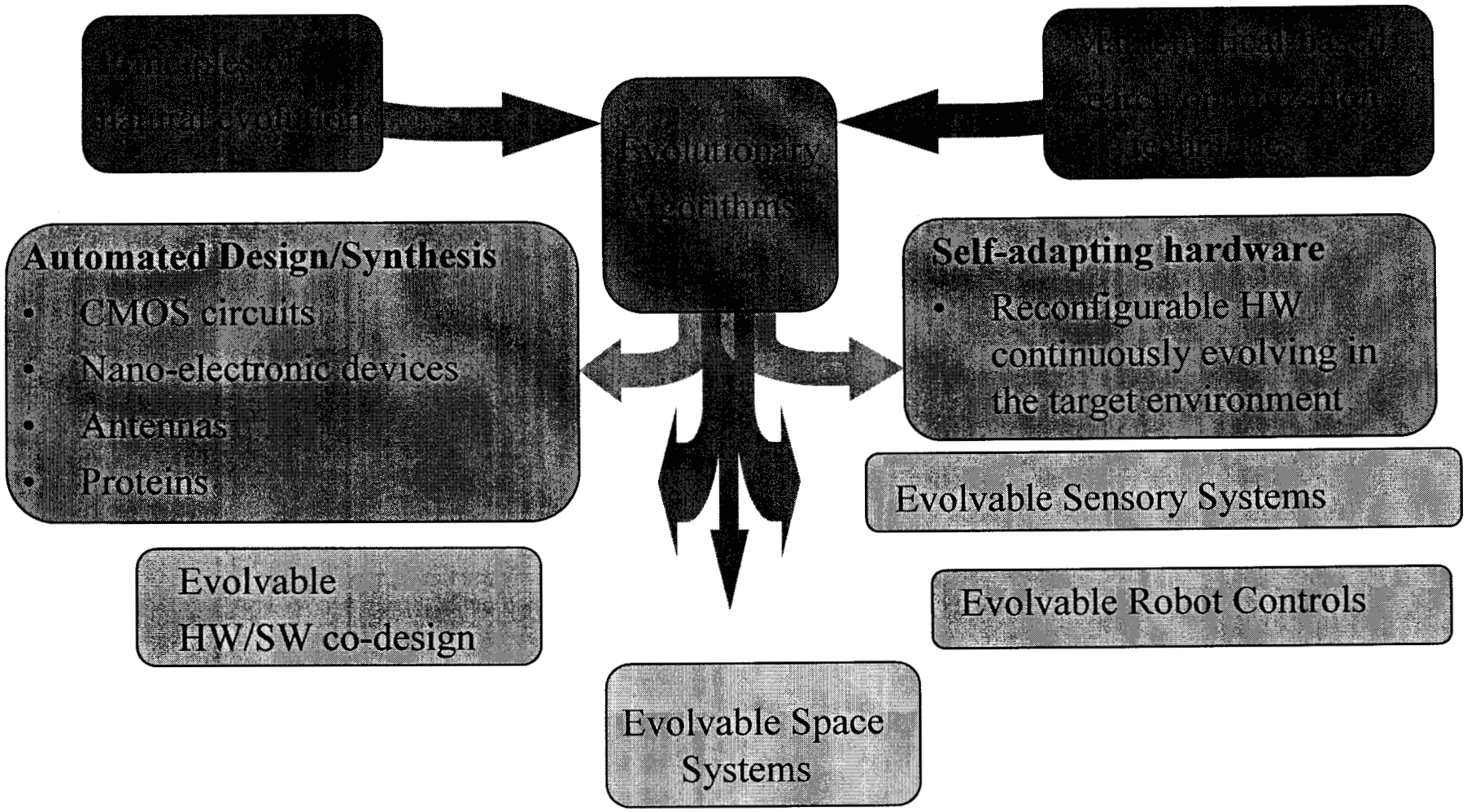
Accelerated evolution, ~ seconds for electronics

Evolutionary synthesis/design of electronic circuits



Potential designs/implementations compete; the best ones are slightly modified to search for even more suitable solutions

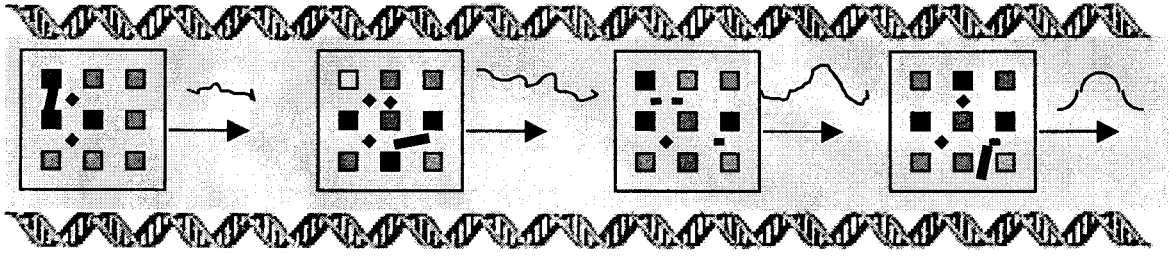
Evolware: from genetically engineered devices to evolvable space systems



Evolvable hardware - an overview

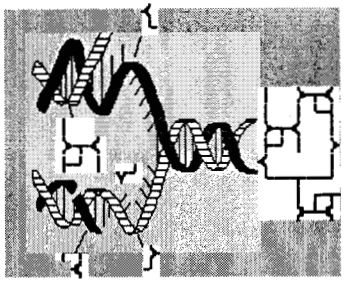
Approach:

- Use re-configurable hardware
- Achieve self-organization by reassigning cell function & interconnections
- Use powerful parallel searches (e.g. genetic algorithms) to evolve the hardware



JPL EHW focus: evolvable micro (& nano) electronics

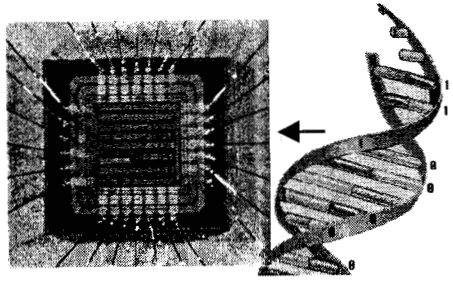
Objective 1: Automated device/circuit/system design/synthesis/optimization



Justification:

- Empirical Design is sub-optimal. Complete design space search is unfeasible.
- Rapid design
- Generation of novel circuits

Objective 2: Develop chips/HW/systems capable of (self-)adaptation to the environment

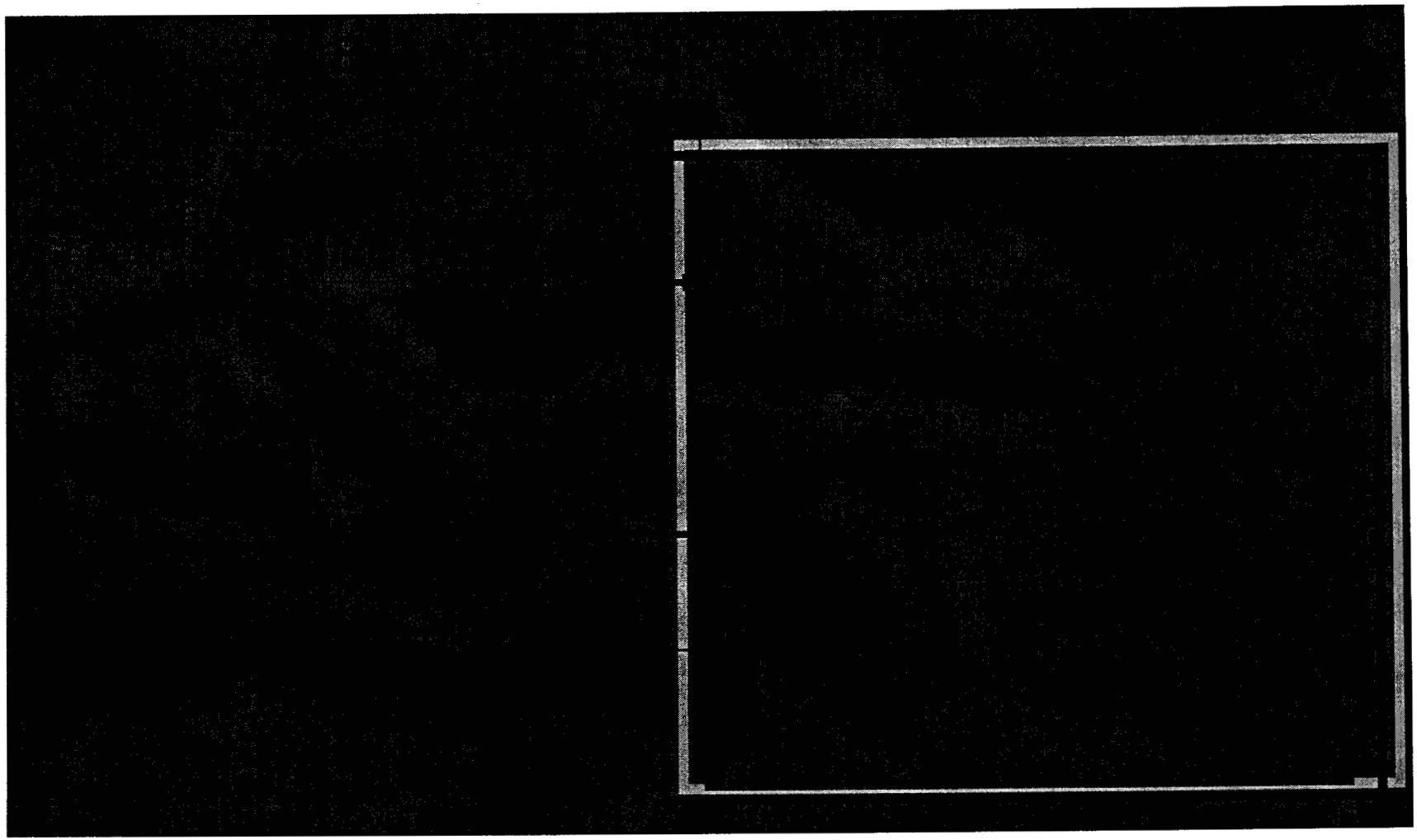


Approach:

- Find appropriate genotype to phenotype mappings
- Use Evolutionary Design Tool with SPICE

- Multi-criteria optimization (power, speed, etc.)
- Automated design in space, without human designer intervention
- Validation for synthesis of new circuits directly in reconfigurable hardware

An Evolutionary Design Tool
(a parallel implementation)



JPL Genetically Engineered NanoElectronic Systems (GENES)

Objective:

- Automated/Rapid nanotechnology device synthesis and development.
- Generation of novel devices.

Approach:

- Augment recently developed advanced NanoElectronic MOdeling (NEMO) tool analyze individual structures in parallel.
- Augment parallel genetic algorithm package (PGApack) to optimize and select desired structures in NEMO.
- Develop graphical user interface to enable access to set of evolutionary quantum device design models.

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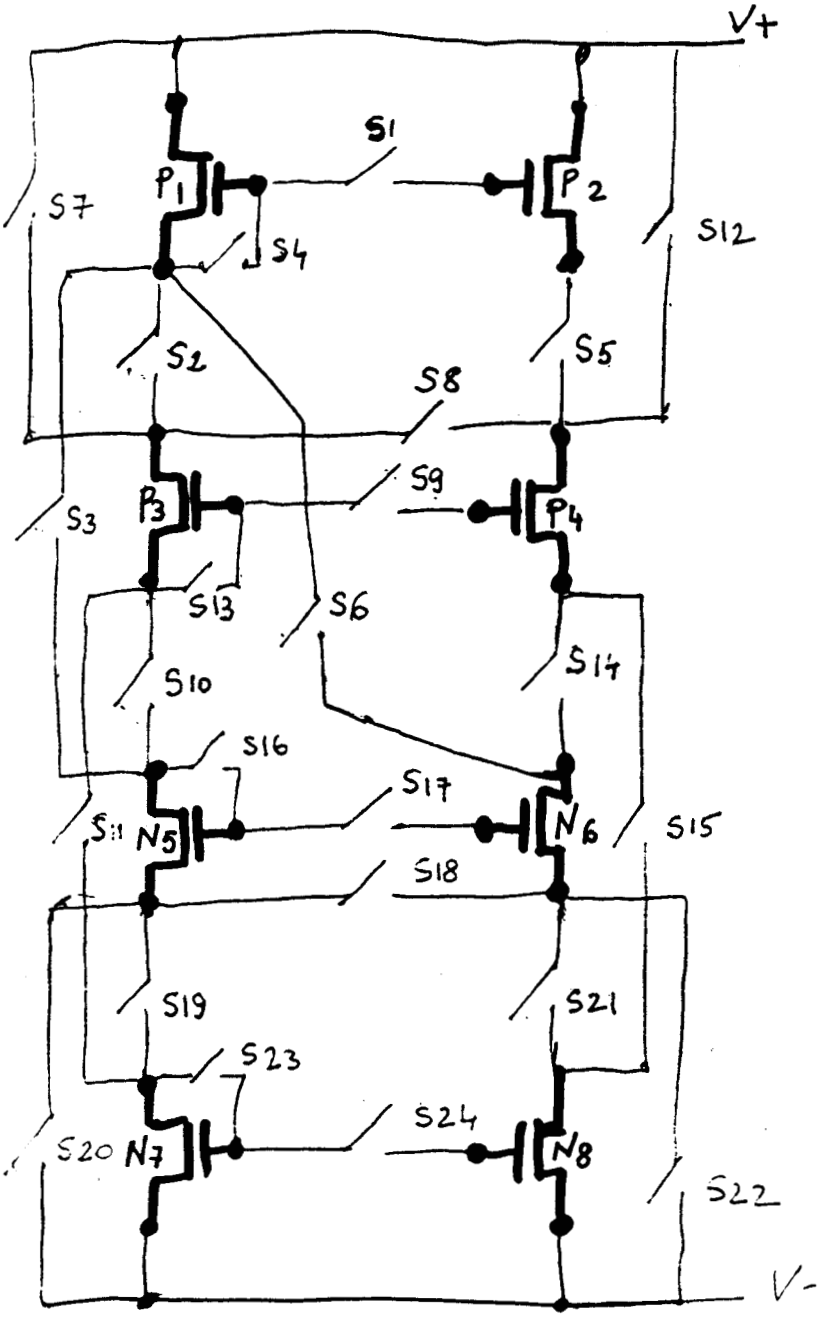
V+
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P1
P2
S7
S4
S12
S2
S5
S8
S9
P3
P4
S3
S13
S6
S14
S10
S16
S17
S11
N5
N6
S15
S18
S19
S21
S23
S24
S20
N7
N8
S22
V-

PROTEA modular architecture

Results of simulated evolution

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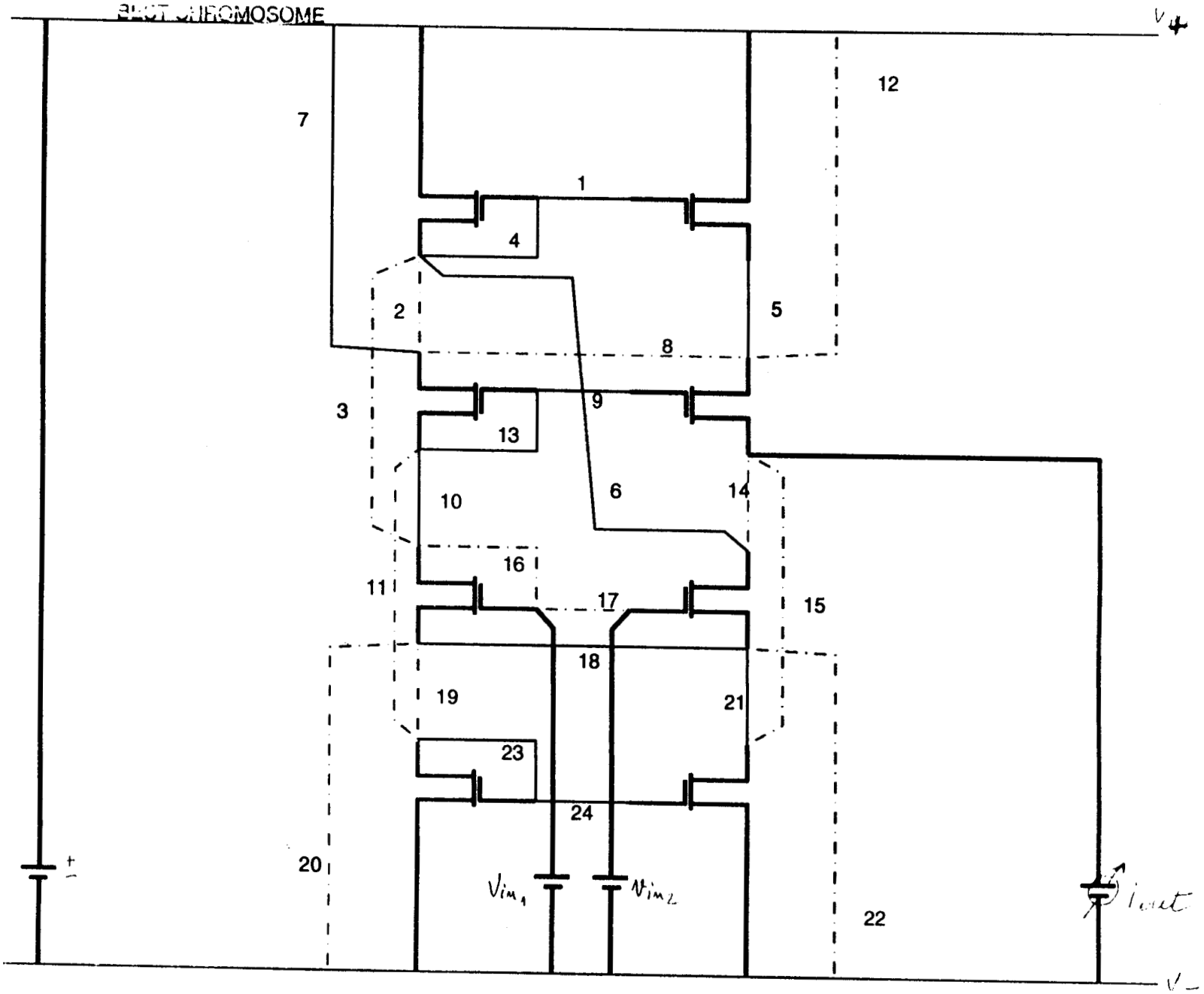


Fig 3

without. annealing-pop-ctrl.ps

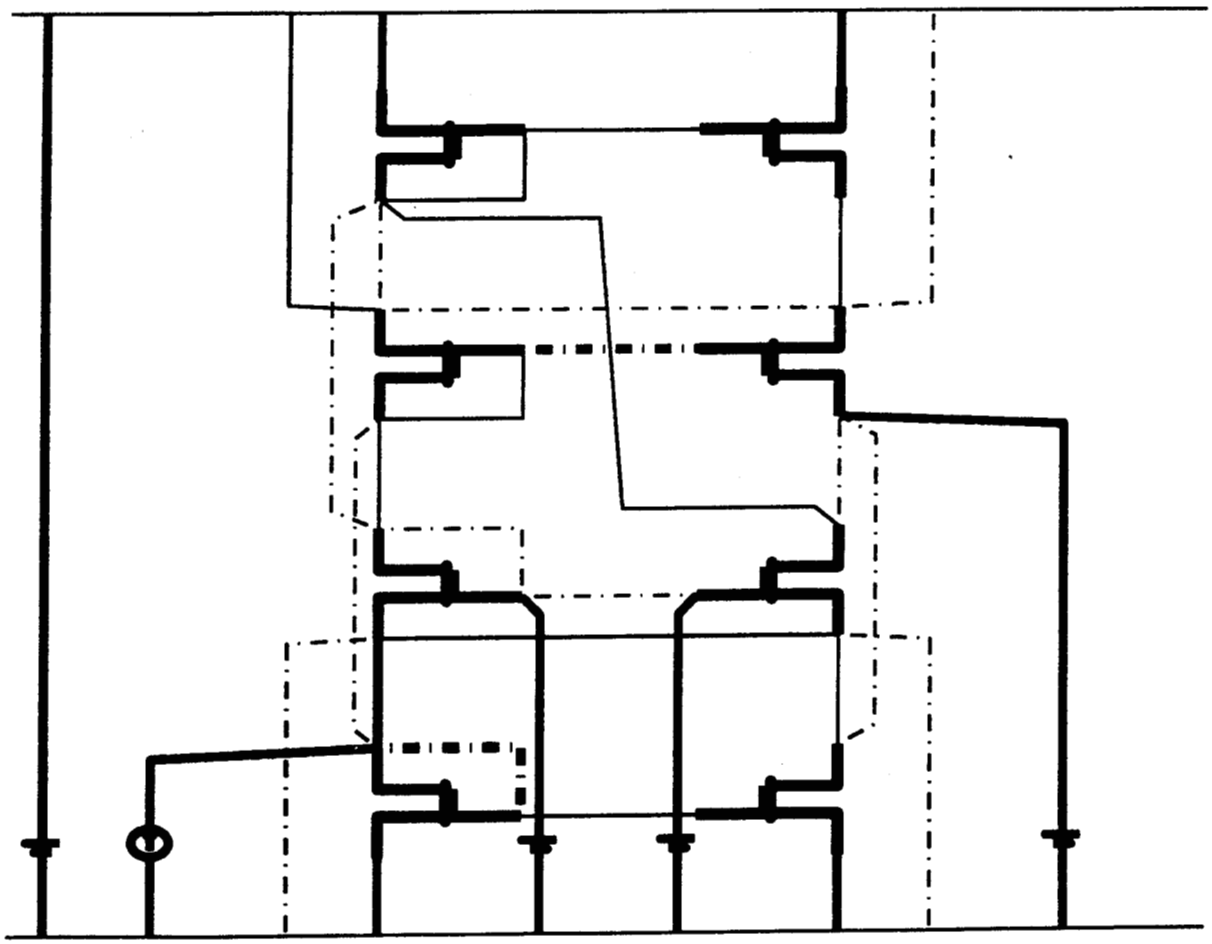


Fig 4.9

without-annealing-pop-cir2.PS

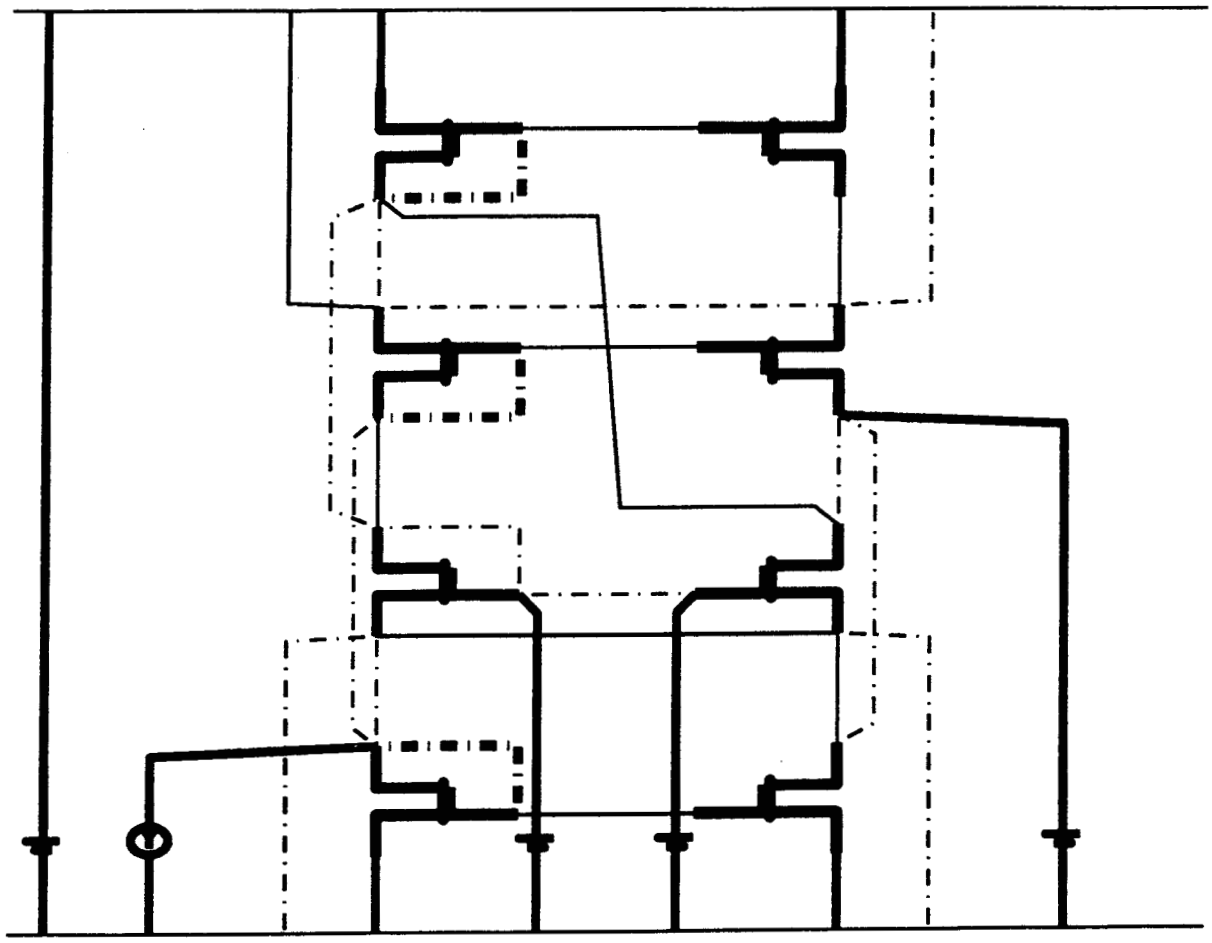


Fig 4.6

without_annealing_pop.ps

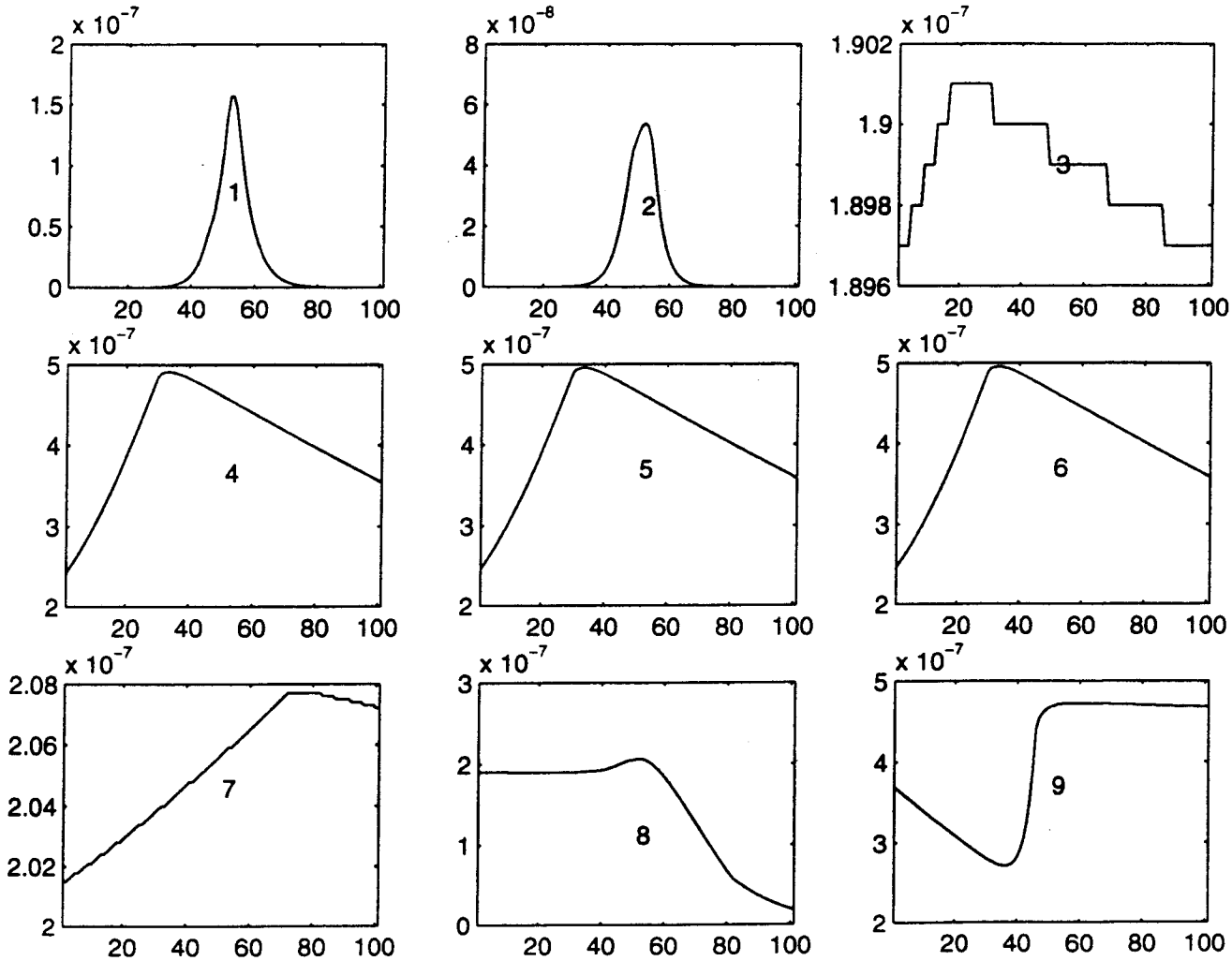
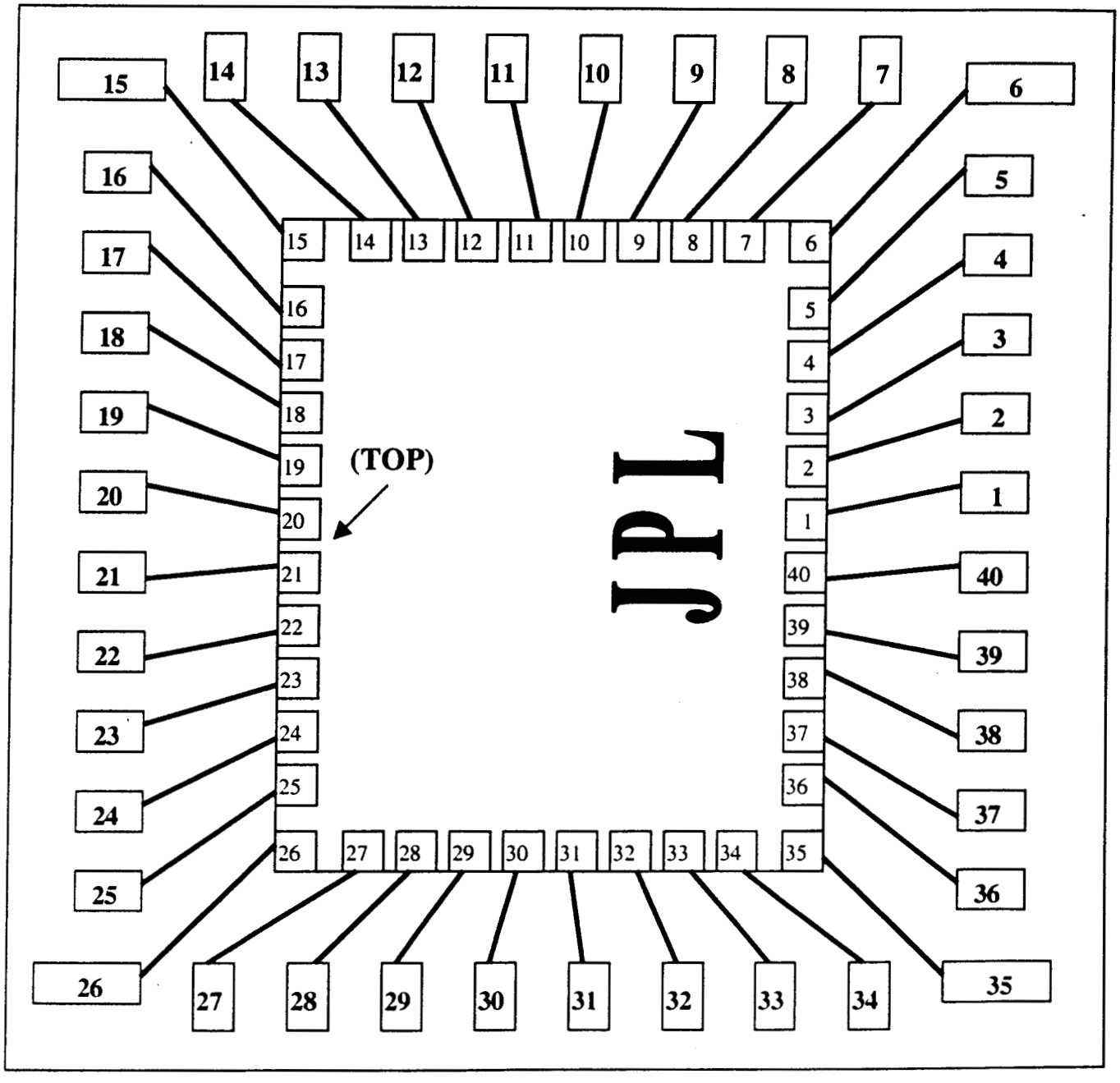
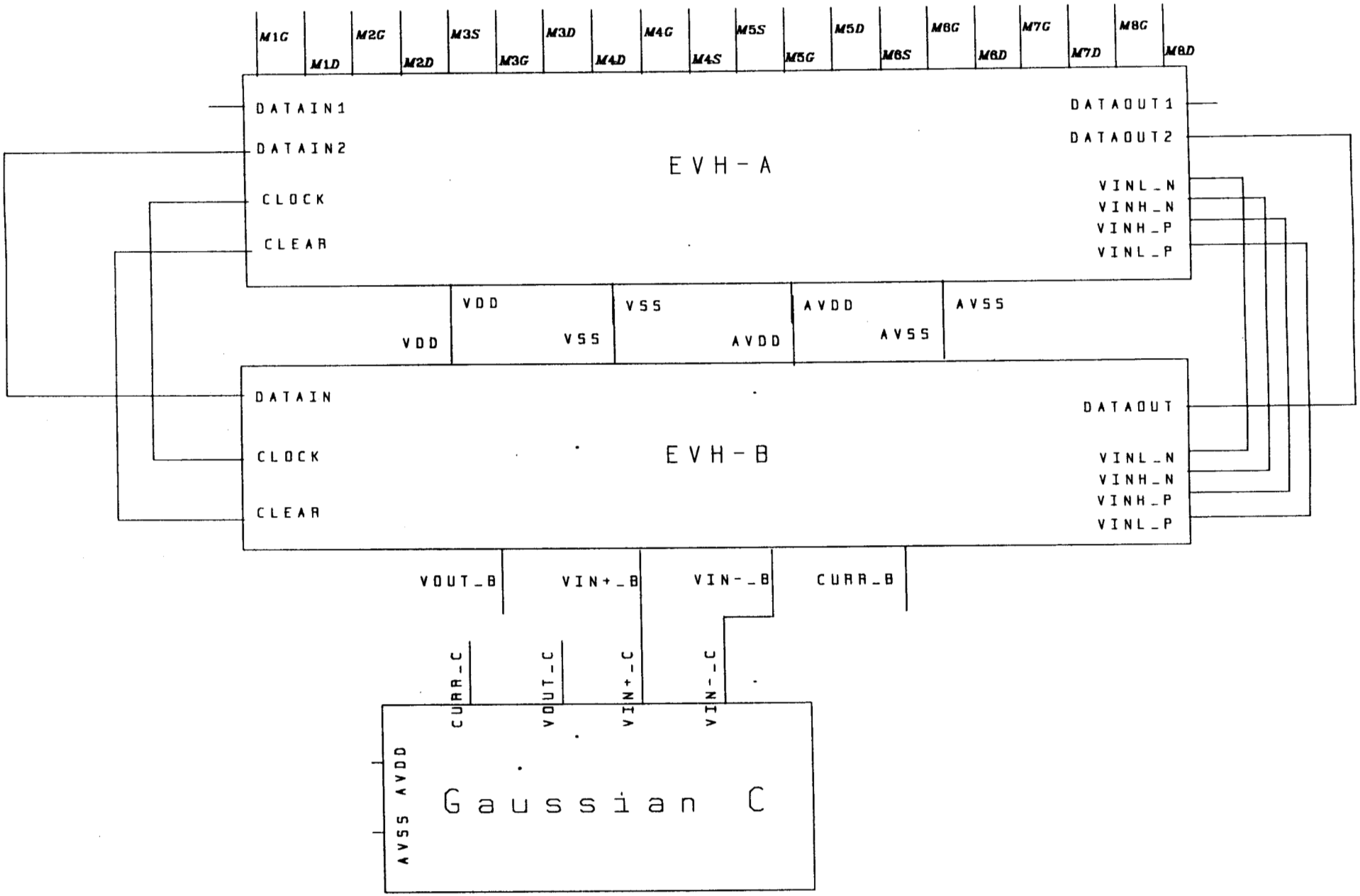


Fig 5

PROTEA chip and its *modus operandi*

Chip Bonding Diagram for EVOLVE1

Project Name: EVOLVE1
Project ID: 56085
Package: DIP40



I V U I V I I (top level schematic)