Automatic design of **trustworthy** sine-wave oscillators using genetic algorithms

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Varun Jain[2]
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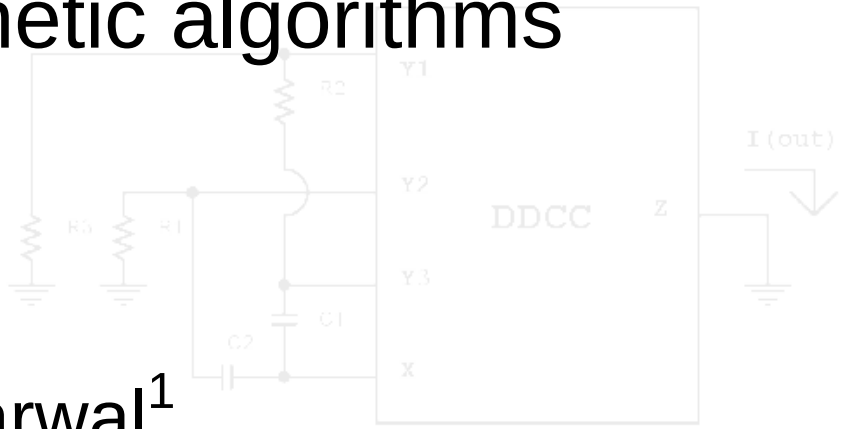
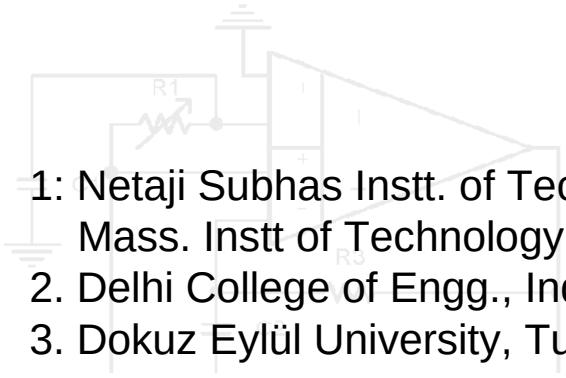
Ugur Cam[3]





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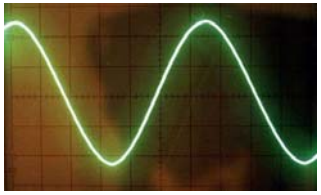
Mass. Instt of Technology, USA
2. Delhi College of Engg., India,
3. Dokuz Eylül University, Turkey

Related publications



- Kilinc, Jain, Aggarwal, Cam, "**Catalogue of Variable Frequency and Single-Resistance-Controlled Oscillators Employing A Single Differential Difference Complementary Current Conveyor**", To appear in Frequenz: Journal of RF-Engineering and Telecommunications (Germany), July-August, 2006

- Aggarwal, Kilinc, Cam, "**Minimum component SRCO and VFO using a single DVCCC**," Accepted, Analog Integrated Circuits and Signal Processing (Springer), 2006

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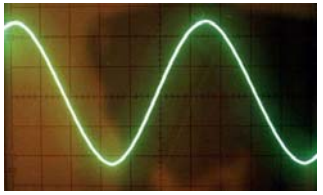
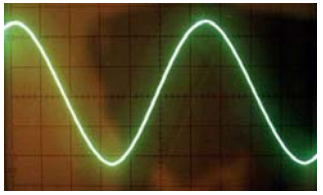
- Aggarwal, "**Evolving Sinusoidal Oscillators Using Genetic Algorithms**", in Proc., The 2003 NASA/DoD Conference on Evolvable Hardware, Chicago, USA, 2003, pp. 67-76.

Design of sine-wave oscillators



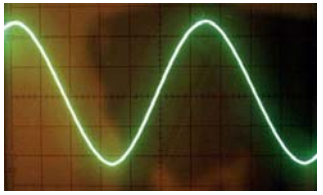
- Sine-wave oscillators have various applications:
  - Communication systems,
  - Control and measurement,
  - Signal processing, etc.
- Interest in design of inductorless low power and low area oscillators

Oscillator Design: How?



- Human designed: Adhoc, intuition, analysis.
- Exhaustive approaches: Mathematically rigorous. Assumedly infeasible with size/topological constraints.
- Explore a small topological space manually.
  - Fixed connection and different elements
  - Use of specific design principle

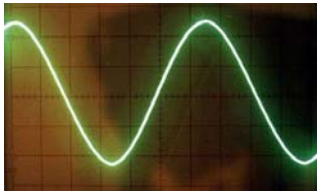
Genetic Algorithm to invent oscillators



Sine-wave oscillator design using **any** linear active element(s)

- Representation: Use of SPICE netlist as genome
- Fitness Evaluation
  - Use of first-order model for active-element.
  - Use of symbolic analysis (NO SPICE invoked)
  - Parse symbolic transfer function to assign fitness.
- Variation Operators: Uniform crossover and mutation
- Selection: Stochastic Universal Selection

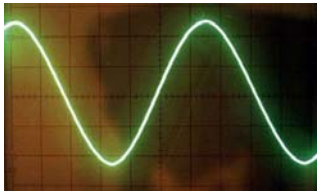
Genetic Algorithm to invent oscillators



- Advantages of symbolic analysis based fitness evaluation
  - Ability to search in otherwise spiked search-space
  - Non-numerical parameter value search.
  - Guarantees human interpretable circuits
  - Most circuits work on SPICE and using discrete components!

A **trustworthy** circuit fulfils two conditions:
1. Can be analyzed and is Human Interpretable.
2. Work on SPICE with high-fidelity models OR actual implementation.

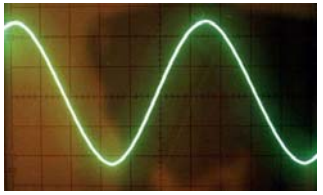
Oscillator Design: How?



- Human designed: Adhoc, intuition, analysis.
- Exhaustive approaches: Mathematically rigorous. Assumedly infeasible with size/topological constrained.
- Explore a small topological space manually.
  - Fixed connection and different elements
  - Use of specific design principle

➢ **Genetic Algorithm:** Push button approach to oscillator synthesis
Automatic, No human designer,
No mathematics,
Looks at complete search space, Scaleable,
Can it find new design ideas?

Desirable properties in an oscillator

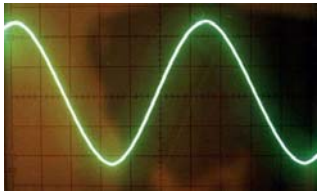


- Control of frequency by a single resistance (Called VFOs, Variable Frequency Oscillators)
- Use of single active element
- Use of least number of resistors and capacitors

Reflect design requirements and desire for

Low power and area

Oscillator Design Research

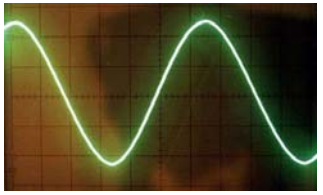


- Late 70’s and early 80’s: Opamp based VFOs:
  5 R and 2 C, 12 oscillators

- Late 90’s:
  Current Conveyor based VFOs
  3 R and 2 C, 2 oscillators

- Late 90’s and 2000:Current Feedback Opamp based oscillators
  3 R and 2 C, 8 oscillators

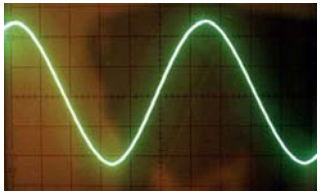
Research Impetus



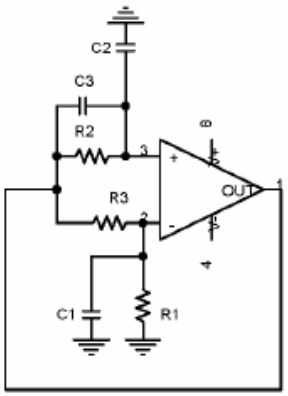
- Oscillators using different active elements to better the state-of-art.

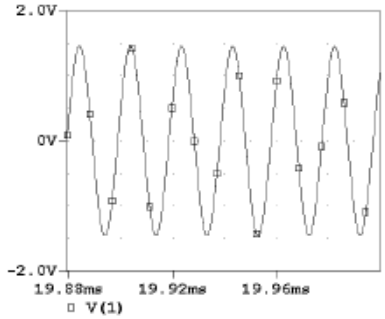
- Oscillators that give explicit current-mode output for current-mode signal processing.

Genetic Algorithm invents topologies Opamp based oscillators

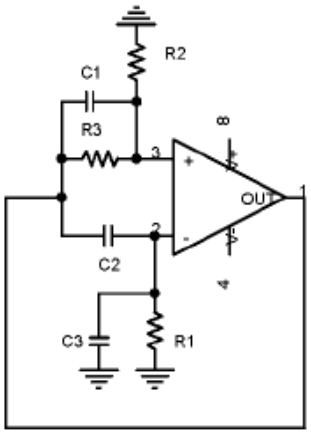


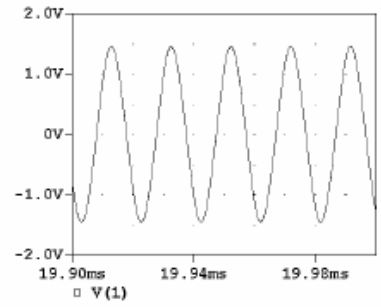
- Reinvents all single Frequency oscillators published by Bhattacharya, et. al. 1984





- Invents new 3 capacitor and 3 resistor based oscillators.





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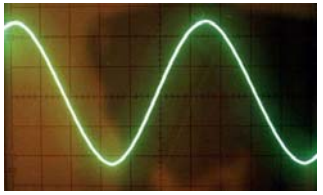
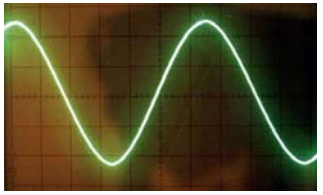
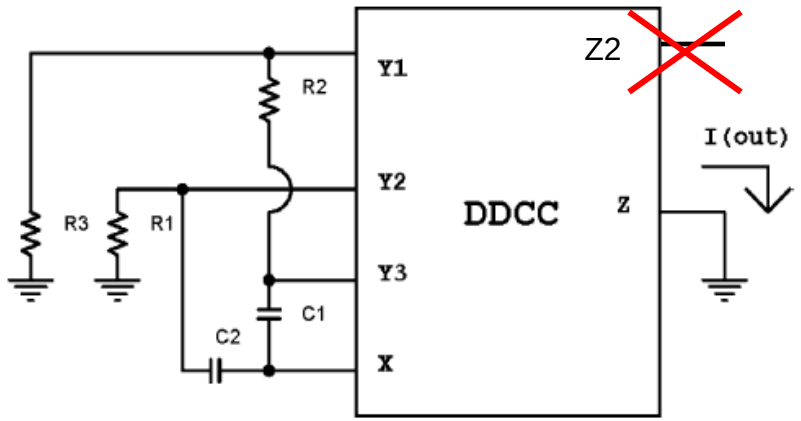


- Invents all SFOs of Bhattacharya and Darkani
  - GA searches the space topological space well.
- Value of result: New oscillators
  - Design beyond imagination.
  - Discovery of new design principle (3 capacitors)
  - Human interpretable and SPICE validated

Genetic Algorithm invents topologies DDCC based oscillator



- Combined all desired properties
  - Used 2 capacitors and 3 resistors (minimum)
  - Single resistor control of frequency.
  - Explicit current mode output
- First oscillator using Differential Difference Current Conveyor
- Earlier, authors postulated need for an additional current terminal
- Only voltage-mode topology using 3R and 2C



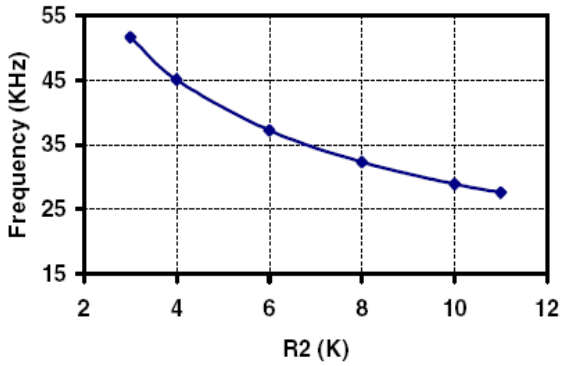
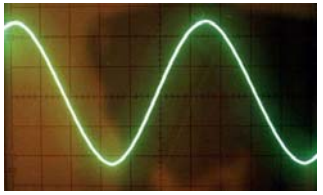


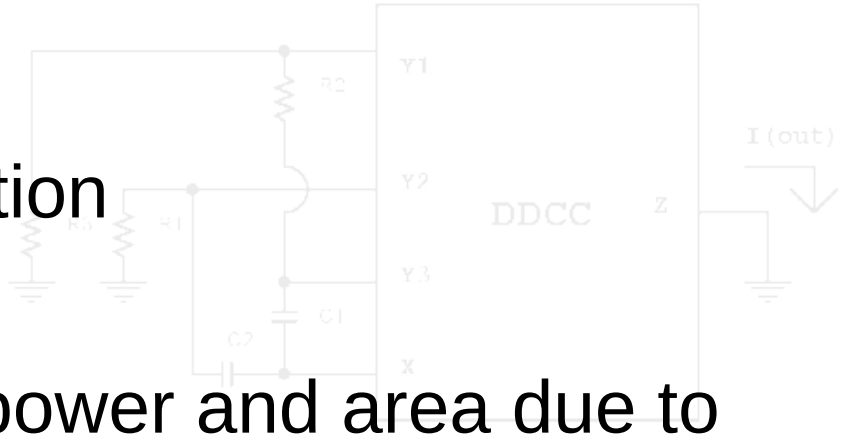
Fig. 2. PSPICE simulation results: Variation of FO with R_2.

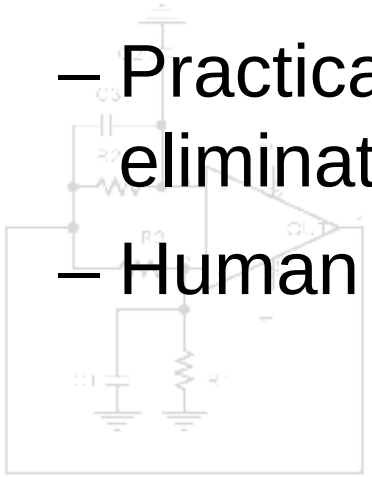
V. Aggarwal, "**Novel Canonic Current Mode DDCC based SRCO synthesized using Genetic Algorithms**" in *Analog Integrated Circuits and Signal Processing*, Vol. 40, 83–85, 2004

Genetic Algorithm invents topologies DDCC based oscillator

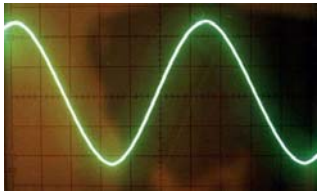


- Value of result
  - Design beyond expectation
  - New design principle
  - Practical Value: Lower power and area due to elimination of additional current terminal.
  - Human interpretable and SPICE validated

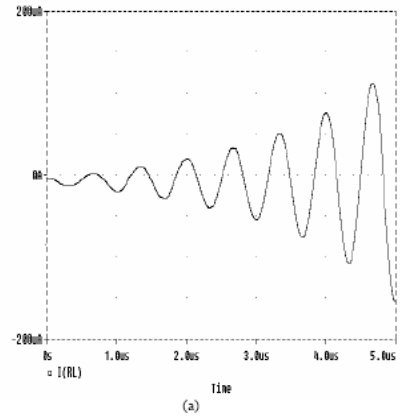


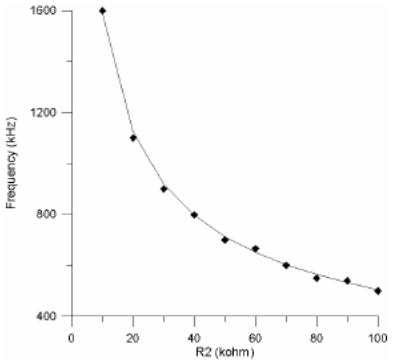


Genetic Algorithm invents topologies Catalogue of DDCCC based oscillators



- Family of 14 oscillators
- All desirable properties
  - Explicit current-mode output
  - Single resistance control of frequency
  - Used 3R and 2C
- SPICE validated with detailed analysis
- Largest catalogue of oscillators using single active element.
- Catalogue includes a unique oscillator





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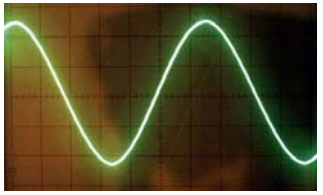
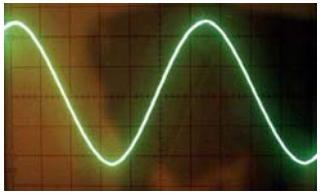


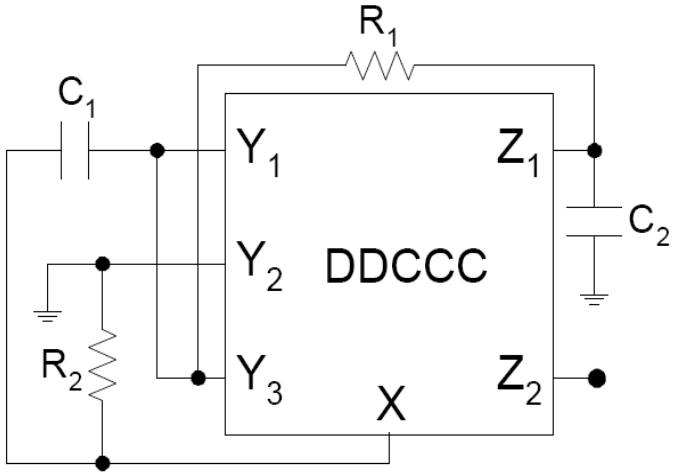
- Value of result:
  - Ability of GA to explore the search space well.
  - Human interpretable and SPICE validated
    (7 stable, 7 unstable with the implementation used).
  - Practical Value: 14 new state-of-art oscillators for the analog designer to choose from.
  - Addition to the state-of-art

Genetic Algorithm invents topologies
Catalogue of DDCCC based oscillators



Oscillator: first of its kind.

- All desirable properties
  - Explicit current-mode output
  - Single resistance control of frequency
  - SPICE validated with detailed analysis
- Uses only **2 resistors and 2 capacitors.**
- Sacrifices independent control of condition of oscillation (not important)
- Uses one resistor less than any other oscillator of its kind.



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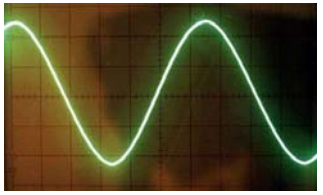
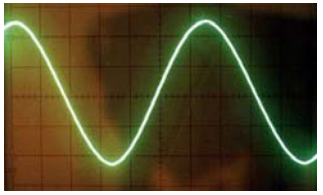
Catalogue of DDCCC based oscillators

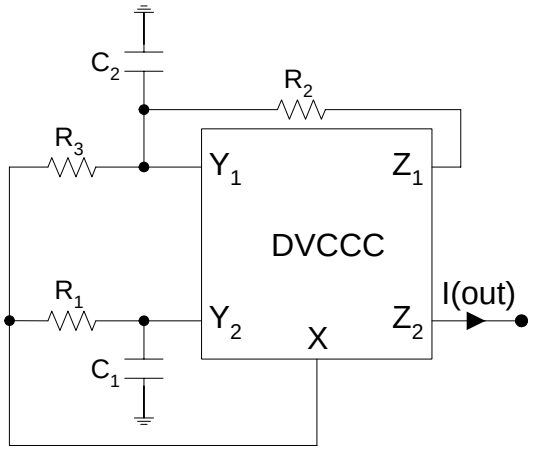


- Value of result
  - Design beyond expectation
  - A new design principle
  - Human interpretable and SPICE validated (Unstable with DDCCC implementation)
  - Improvement over the state-of-art: Lower in power and area.

Genetic Algorithm invents topologies Grounded Capacitor oscillators



- Oscillator-1 using DVCCC
- Combined all properties
  - Used 2 capacitors and 3 resistors
  - Single resistor control of frequency.
  - Explicit current mode output
- **Uses only Grounded capacitors**
- **Value of result**
  - Usefulness of searching the whole search space.
    - Not discovered in oscillator synthesis strategy of Gupta, Senani, 2005.
  - Addition to state-of-art
  - Human Interpretable and SPICE validated.



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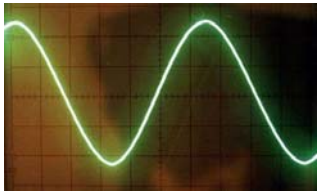
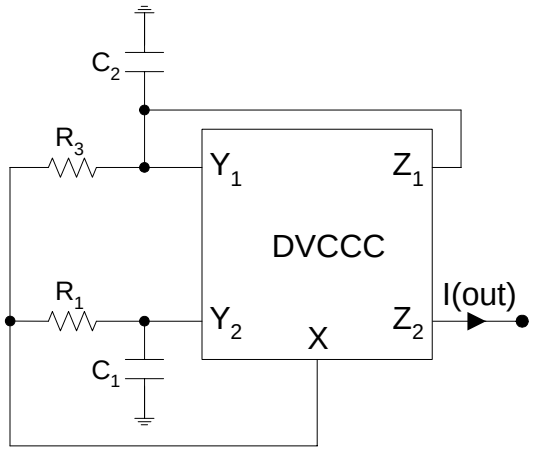
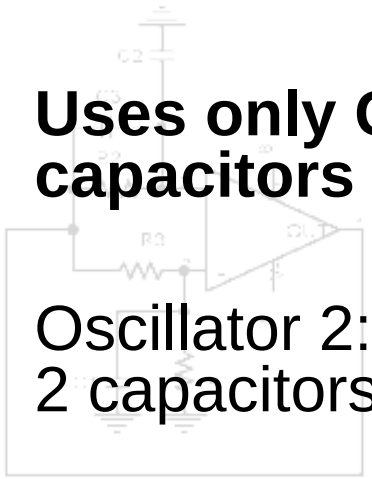


- Oscillator-2 using DVCCC

- Combined all properties
  - Used 2 capacitors and 3 resistors (minimum)
  - Single resistor control of frequency.
  - Explicit current mode output



- **Uses only Grounded capacitors**



- Oscillator 2: Only 2 resistors and 2 capacitors!

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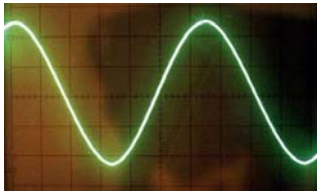
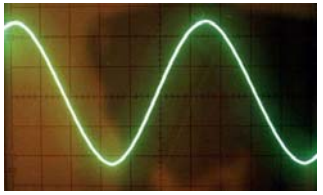
Genetic Algorithm invents topologies Grounded Capacitor oscillators



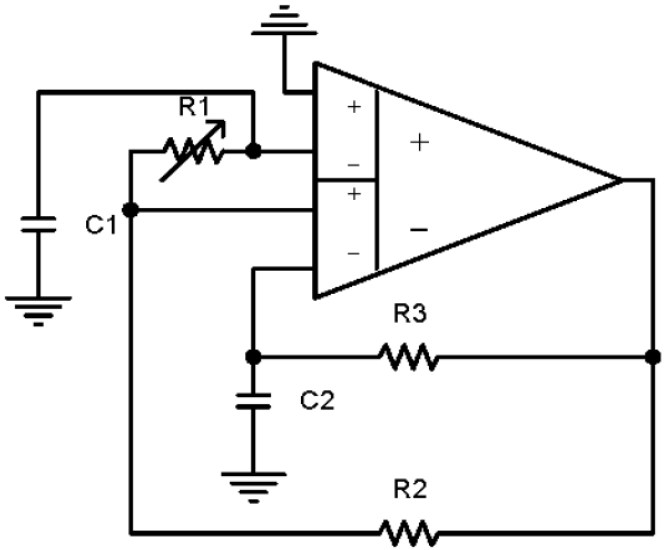
Oscillator-2: Value of result:

- Beyond expectation
- New Design principle
- Usefulness of searching the whole search space.
- **Improves state-of-art**
  - Combines all desirable properties including gnded capacitors. Uses only 4 passive components.
- Human Interpretable and SPICE validated.

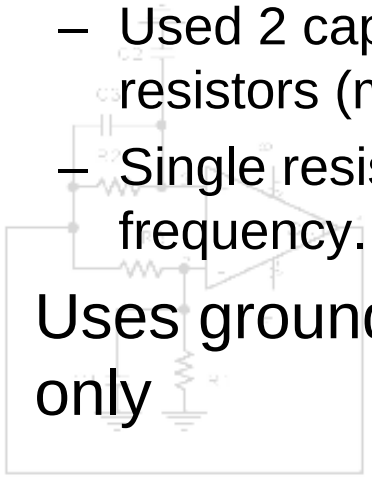
Genetic Algorithm invents topologies Grounded Capacitor oscillators



- Differential Difference Amplifier based voltage mode oscillator

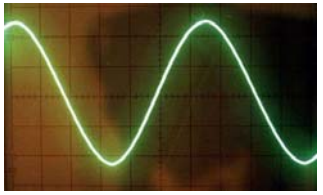


- Combined all properties
  - Used 2 capacitors and 3 resistors (minimum)
  - Single resistor control of frequency.
- Uses grounded capacitors only



New Result!
To be published soon ☺

Genetic Algorithm invents topologies Grounded Capacitor oscillators



Only oscillator of its kind

- Voltage mode grounded capacitor VFO
- Uses minimum passive elements, 3R and 2C
- Uses an already existing widely used active element
- Can be implemented using a discrete IC.

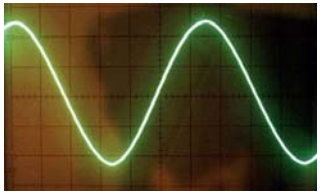
Cam, Toker, Cicekoglu and Kuntman's oscillator using FTFN (Fig. 2, Oscillator 1 of [14])	2000	×	5	both	√	×	√	×	×
Lee and Wang's oscillator using FTFN$^+$ (Fig. 1 of [15])	2001	×	3	both	√	×	×	×	×
Bhaskar's oscillator using FTFN$^+$ (Fig. 1 of [16])	2002	×	4	both	√	√	×	×	×
Ozcan, Toker, Acar and Kuntman's oscillators using CDBA (Oscillators 1-4, 6 in Table 1 of [22])	2000	×	3	FO	√	×	×	√	×
Cam's oscillator using OTRA (Fig. 1 of [17])	2002	×	3	FO	√	×	×	√	×
Gupta and Senani's oscillator using DVCCC (Fig. 1 of [23])	2000	×	3	both	√	√	√	×	×
Gunes and Toker's oscillators using DVCFA (Oscillators A1-B3, A1-B4, A2-B3, A2-B4 in Table 3*a* of [24])	2002	×	3	both	√	√	×	√	×
Chang, Al-Hashimi, Chen, Tu and Wan oscillators using FDCCII (Figs. 1 and 2 of [26])	2002	×	3	both	√	√	√	×	×
New SRCOs using DDCCFA	new	×	3	both	√	√	√	√	√

'Canonic' refers to the circuits using only two capacitors

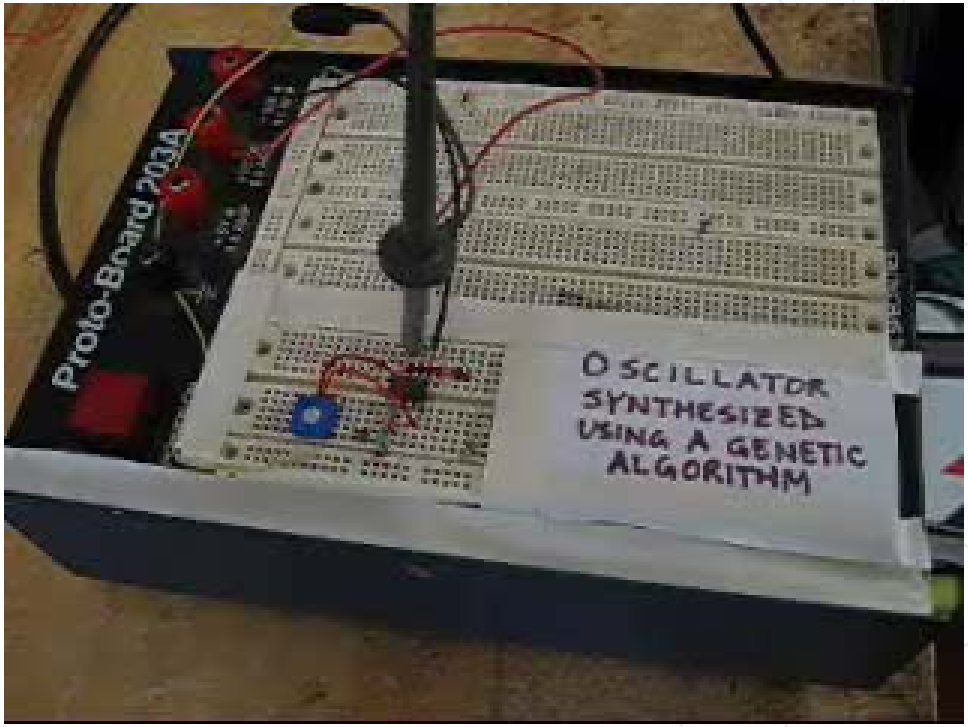
∗∗ explicit CM with ideally ∞ output impedance and explicit VM with ideally zero output impedance

Yr: year of publication; CA: commercial availability of the ABB; *N*: number of resistors used; SRC: SRC of CO/FO; S: simple CO (no more than one condition); E: employment of two GCs

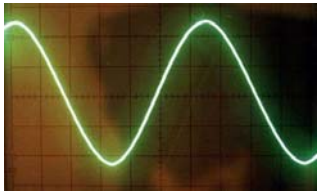
Genetic Algorithm invents topologies Grounded Capacitor oscillators



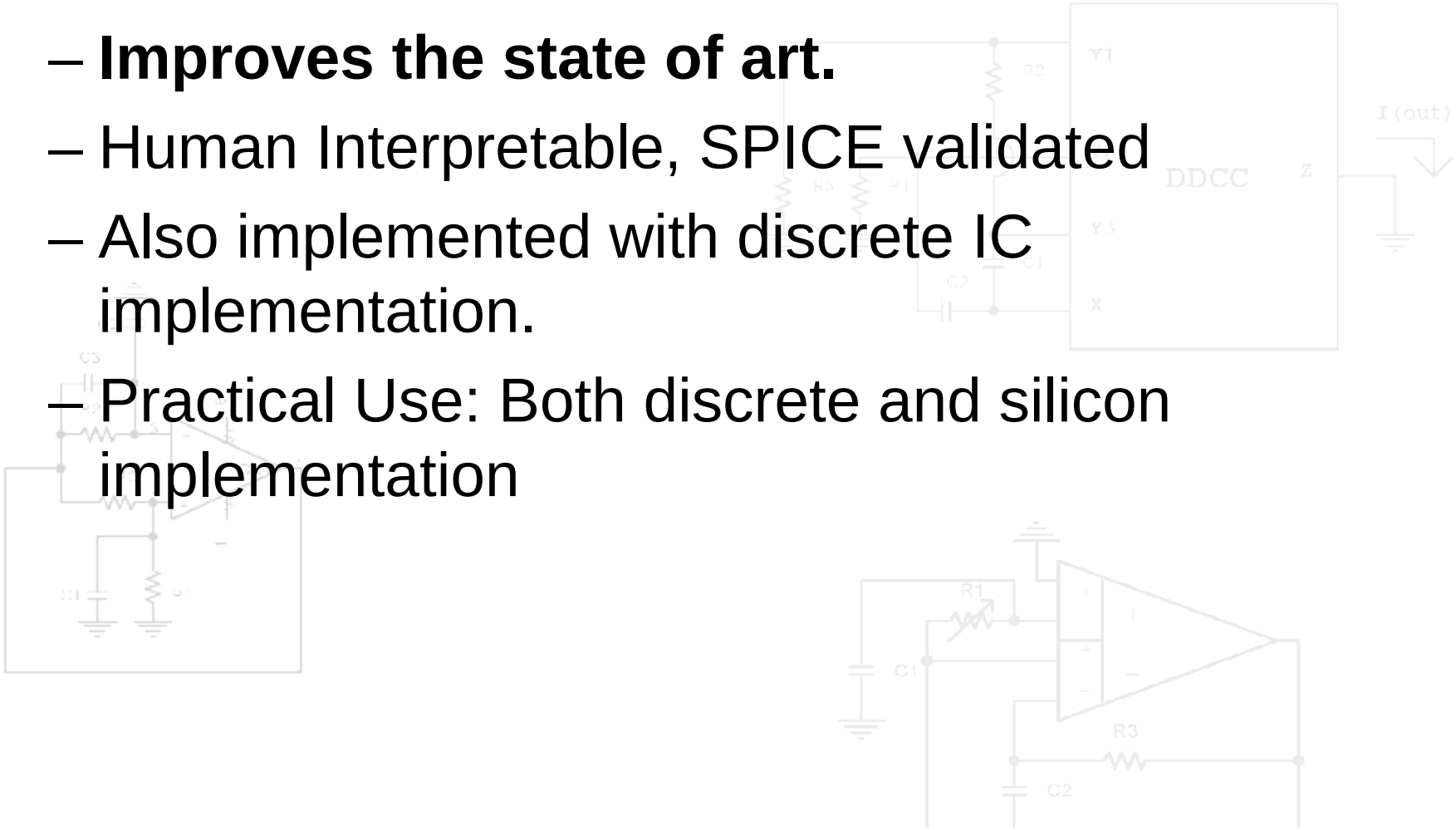
- Of course, it works using actual components!
- Used AD830



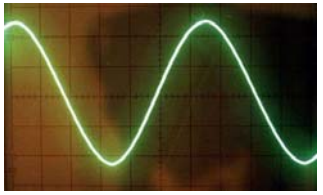
Genetic Algorithm invents topologies Grounded Capacitor oscillators



- Value of result
  - **Improves the state of art.**
  - Human Interpretable, SPICE validated
  - Also implemented with discrete IC implementation.
  - Practical Use: Both discrete and silicon implementation

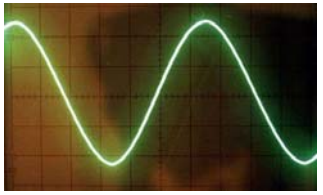


Genetic Algorithm invents oscillators



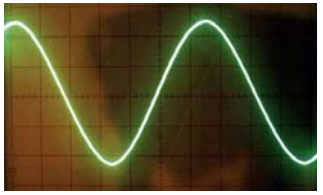
- Opamp based oscillators
  - Rediscovery and New design principle
- DDCC based oscillator
  - New design principle, Lower area and power
- DDCCC based catalogue of oscillators
  - New useful topologies, new design principle
- DVCCC based oscillator
  - The only oscillator of its kind, Improvement to state-of-art.
- DDA based oscillator
  - The only oscillator of its kind, Improvement to state of art.

Why Human-Competitive?



- Results equal or improve state-of-art in oscillator design.
- Human Interpretable and SPICE validated.
- Not only of intellectual value, but of practical use.
- Discover interpretable new design principles.
- Generic to design of oscillators using any or multiple active elements.
- Accepted in analog design journals as a result in their own.

Acknowledgments



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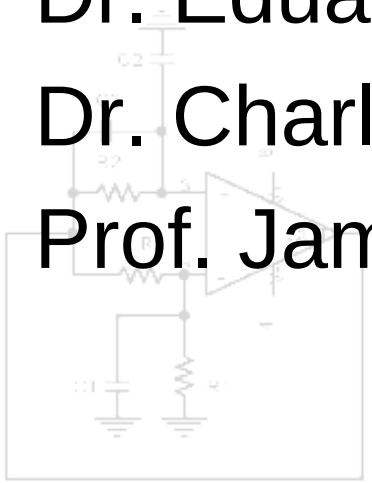
- Prof. James Grimbleby



Thank you!

Suggestions, comments

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