RFIC-Lab @ ECE-TUT, Finland

**Founded:** 1995 in Dpt. Communications
**Team:** 15+34 BSc, MSc & PhD
**CAD:** 50 Cadence Licenses
**Measurements:** Up to 27GHz On-Wafer
**Teaching:** 9 courses: Com. RF-IC

**Partners:** Bell-Labs, IBM, Infineon, Intel, Nokia, STMicro, TI.
**Funding:** 9.4 Mln.USD
**Patents:** 46 (W-4, USA-12, UK-8 …)
**Publications:** 98 (25 in IEEE)

GHz-range-IC: VCO, DCO, T&H, LNA, DCDC

Some Key Publications:

Tampere University of Technology
RFIC Laboratory, Department of Electronics and Communications Engineering
Prof. Nikolay T. Tchamov
Korkeakoulunkatu-1, TH-108 33720 – Tampere, Finland
+358-(0)40-582-5915
www.cs.tut.fi/tlt/rfasic
Page 1 / 8

Nov-2013

nikolay@cs.tut.fi

Published Main R & D Achievements

Two-Phase Self-Assisted Zero-Voltage Switching DCDC Converter,

Q-factor analysis for C-C LC oscillators using TVRL,

Design consideration in tapped-inductor 4th-order Dual-Band VCO,

A Darlington-Enhanced CMOS Oscillator Architecture

Evaluation & Comparison GHz-range LC Oscillators using TVRL,

UMTS and GSM Low Phase Noise Inductively Tuned LC VCO,

Time-Varying Root Locus of Large-Signal LC Oscillators,
IEEE Tr. CAD IC and Sys, no. 5, May 2010.

Flicker Noise Up-Conversion Suppression in Differential LC Oscillators,
IEEE Tr. on CAS-2, no.11, Nov 2007.

Wideband Low Phase-Noise LC-VCO With Programmable $K_{vco}$,

Dual-Band LC VCO Architecture With a Fourth-Order Resonator,

Novel VCO Using Series Above-IC FBAR and Parallel LC Resonator,
IEEE Journal Solid-State Circuits, no.10.

Differential Pre-Compensated GHz-range Low-voltage Track-and-Hold,
IEE EL, no.2, Jan 2003.

Monolithic RF Bandpass Track-and-Hold,
IEE EL, no.2, Jan 2003.

3.6 GHz Double Cross-Coupled Multivibrator VCO 1.6 GHz Tuning,

High-Performance Differential VCO Based on Armstrong Oscillator,

4.3 GHz VCO with 2-GHz Tuning Range and Low Phase Noise,
In 2012 Worldwide operate about 300,000 El.ForkLifts
Battery Energy Equivalent to 5,900,000 Hybrid Cars

Toyota Prius 2012 (ZVW30)
4.4 kW Lithium-Ion, 201.6 V
4 hours/day,
250 days/year
1,100 kWh/year

Toyota Traigo 1800Kg
(8FBET18)
36kWh Lead Acid, 48V
24 hours/day,
2 packs/day
250 days/year
18,000 kWh/year

200 V --- Voltage --- 48V !

People --- Transport --- Materials
Many --- Restrictions --- Few

'16' = '1'

When? --- Needed --- Now !

Japanese --- Maker --- Who ?
Fork-Lift-Market and related Battery-Market

Worldwide lift truck market

<table>
<thead>
<tr>
<th>Region</th>
<th>Orders 2009</th>
<th>Orders 2010</th>
<th>% Change</th>
<th>Shipments 2009</th>
<th>Shipments 2010</th>
<th>% Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Europe</td>
<td>200,311</td>
<td>259,932</td>
<td>130%</td>
<td>207,082</td>
<td>245,512</td>
<td>119%</td>
</tr>
<tr>
<td>Americas</td>
<td>118,929</td>
<td>181,060</td>
<td>152%</td>
<td>128,246</td>
<td>152,160</td>
<td>119%</td>
</tr>
<tr>
<td>Asia</td>
<td>206,531</td>
<td>322,953</td>
<td>156%</td>
<td>207,207</td>
<td>314,307</td>
<td>152%</td>
</tr>
<tr>
<td>Africa</td>
<td>9,721</td>
<td>15,534</td>
<td>160%</td>
<td>9,953</td>
<td>14,243</td>
<td>143%</td>
</tr>
<tr>
<td>Oceania</td>
<td>11,340</td>
<td>14,973</td>
<td>132%</td>
<td>12,451</td>
<td>14,468</td>
<td>116%</td>
</tr>
<tr>
<td>Total</td>
<td>546,832</td>
<td>794,452</td>
<td>145%</td>
<td>561,939</td>
<td>740,690</td>
<td>132%</td>
</tr>
</tbody>
</table>

Source: These figures are from the World Industrial Truck Statistics organization.

Top 20 lift truck suppliers in 2010

<table>
<thead>
<tr>
<th>Rank</th>
<th>Company</th>
<th>2009 Rank</th>
<th>2010 revenue*</th>
<th>North American brands</th>
<th>World headquarters</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Toyota Industries Corp.</td>
<td>1</td>
<td>$5.9 billion</td>
<td>Toyota, Raymond</td>
<td>Aichi, Japan</td>
</tr>
<tr>
<td>2</td>
<td>Kion Group</td>
<td>2</td>
<td>$4.7 billion</td>
<td>Linde, Still OM, Baoli</td>
<td>Wiesbaden, Germany</td>
</tr>
<tr>
<td>3</td>
<td>Jungheinrich Lift Truck Corp.</td>
<td>3</td>
<td>$2.4 billion</td>
<td>Jungheinrich</td>
<td>Hamburg, Germany</td>
</tr>
<tr>
<td>4</td>
<td>Crown Equipment Corp.</td>
<td>4</td>
<td>$1.8 billion</td>
<td>Crown, Hamech</td>
<td>New Bremen, Ohio</td>
</tr>
<tr>
<td>5</td>
<td>NACCO Industries</td>
<td>5</td>
<td>$1.8 billion</td>
<td>Hyster, Yale</td>
<td>Cleveland, Ohio</td>
</tr>
<tr>
<td>6</td>
<td>Mitsubishi Caterpillar Forklift</td>
<td>6</td>
<td>$1.2 billion</td>
<td>Mitsubishi, CAT</td>
<td>Sagamihara, Japan</td>
</tr>
<tr>
<td>7</td>
<td>Komatsu Utility Co.</td>
<td>7</td>
<td>$1 billion</td>
<td>Komatsu, Tok</td>
<td>Tokyo, Japan</td>
</tr>
<tr>
<td>8</td>
<td>Nissan Forklift Corp.</td>
<td>9</td>
<td>$900 million</td>
<td>Nissan, Barrett, Atlet</td>
<td>Tokyo, Japan</td>
</tr>
<tr>
<td>9</td>
<td>TCM Corp.</td>
<td>10</td>
<td>$889 million</td>
<td>TCM</td>
<td>Tokyo, Japan</td>
</tr>
<tr>
<td>10</td>
<td>Hangzhou Forklift Group</td>
<td>13</td>
<td>$747 million</td>
<td>Not available in North America</td>
<td>Tokyo, Japan</td>
</tr>
<tr>
<td>11</td>
<td>Clark Material Handling</td>
<td>13</td>
<td>$570 million</td>
<td>Clark</td>
<td>Seoul, South Korea</td>
</tr>
<tr>
<td>12</td>
<td>Doosan Infracore</td>
<td>12</td>
<td>$475 million</td>
<td>Clark</td>
<td>Seoul, South Korea</td>
</tr>
<tr>
<td>13</td>
<td>Zhejiang Hangcha Engineering Machinery Co.</td>
<td>15</td>
<td>$313 million**</td>
<td>Heli</td>
<td>Hangzhou, China</td>
</tr>
<tr>
<td>14</td>
<td>Hyundai Heavy Industries</td>
<td>15</td>
<td>$258 million</td>
<td>Hyundai</td>
<td>Ulsan, South Korea</td>
</tr>
<tr>
<td>15</td>
<td>Tai Lift</td>
<td>17</td>
<td>$125 million**</td>
<td>Tai Lift, World-Lift</td>
<td>Taichung, Taiwan</td>
</tr>
<tr>
<td>16</td>
<td>Combilift</td>
<td>18</td>
<td>$110 million</td>
<td>Combilift</td>
<td>Monaghan, Ireland</td>
</tr>
<tr>
<td>17</td>
<td>Hubtex</td>
<td>20</td>
<td>$75 million**</td>
<td>Hubtex</td>
<td>Fulda, Germany</td>
</tr>
<tr>
<td>18</td>
<td>Hyster</td>
<td>20</td>
<td>$69 million</td>
<td>Hyster</td>
<td>Shanghai, China</td>
</tr>
<tr>
<td>20</td>
<td>Godrej &amp; Boyce Manufacturing</td>
<td>NA</td>
<td>$67 million</td>
<td>Not available in North America</td>
<td>Mumbai, India</td>
</tr>
</tbody>
</table>

*Fiscal year 2010 worldwide sales revenue figures based on foreign exchange rates as of 12/31/10.
**Figures based on industry estimate.

Note: All figures are rounded; the base year is 2009. Source: Frost & Sullivan

EV Battery Market: Demand by Geographic Region (World), 2009

- North America: 33.0%
- Europe: 24.9%
- Asia Pacific: 24.9%
- Latin America: 3.7%
- Rest-of-World: 4.3%

Note: All figures are rounded; the base year is 2009. Source: Frost & Sullivan

Tampere University of Technology
RFIC Laboratory, Department of Electronics and Communications Engineering
Prof. Nikolay T. Tchamov
Korkeakoulunkatu-1, TH-108
33720 – Tampere, Finland

+358-(0)40-582-5915
www.cs.tut.fi/tlt/rfasic
Page 4 / 8
nakolay@cs.tut.fi
Nov-2013
## Financial Impact: Energy Recovery in Fork-Lifts

**Example:** Toyota Traigo48: 1800Kg, 7.5m lifting; Model 8FBE18, 750Ah, 48V

<table>
<thead>
<tr>
<th>Battery</th>
<th>Charge per night</th>
<th>Working days</th>
<th>Charge per year</th>
</tr>
</thead>
<tbody>
<tr>
<td>48V 750Ah</td>
<td>36 kWh</td>
<td>250</td>
<td>9000 kWh</td>
</tr>
</tbody>
</table>

### Cost of the Electricity

<table>
<thead>
<tr>
<th>Country</th>
<th>€/kWh</th>
<th>Average €/kWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Belgium</td>
<td>0.2235</td>
<td>0.20</td>
</tr>
<tr>
<td>Denmark</td>
<td>0.3106</td>
<td>0.3106</td>
</tr>
<tr>
<td>Finland</td>
<td>0.1588</td>
<td>0.1588</td>
</tr>
<tr>
<td>France</td>
<td>0.1492</td>
<td>0.1492</td>
</tr>
<tr>
<td>Germany</td>
<td>0.2708</td>
<td>0.2708</td>
</tr>
<tr>
<td>Italy</td>
<td>0.2184</td>
<td>0.2184</td>
</tr>
<tr>
<td>Spain</td>
<td>0.2082</td>
<td>0.2082</td>
</tr>
<tr>
<td>Sweden</td>
<td>0.1892</td>
<td>0.1892</td>
</tr>
<tr>
<td>UK</td>
<td>0.0867</td>
<td>0.0867</td>
</tr>
</tbody>
</table>

### Charger Efficiency & Battery Efficiency

- Charger Efficiency = 80% (usually 70-90%)
- Battery Efficiency = 75% (usually 50-85%)
- Total Battery Charging Efficiency = 60%

### The COST OF THE ELECTRICITY

<table>
<thead>
<tr>
<th>Cost</th>
<th>Per Day</th>
<th>Per Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>€</td>
<td>8.05</td>
<td>2012</td>
</tr>
<tr>
<td>€</td>
<td>11.18</td>
<td>2796</td>
</tr>
</tbody>
</table>

### Today’s Energy Recovery

<table>
<thead>
<tr>
<th>Energy Recovery</th>
<th>Savings for 100 Lift-Trucks</th>
<th>Savings for 300 Lift-Trucks</th>
</tr>
</thead>
<tbody>
<tr>
<td>20% Total</td>
<td>€ 67082</td>
<td>€ 201185</td>
</tr>
<tr>
<td>80% Target</td>
<td>€ 47554</td>
<td>€ 129922</td>
</tr>
</tbody>
</table>

### Then the Difference

<table>
<thead>
<tr>
<th>Difference</th>
<th>Savings for 100 Lift-Trucks</th>
<th>Savings for 300 Lift-Trucks</th>
</tr>
</thead>
<tbody>
<tr>
<td>20% to 80%</td>
<td>€ 202886</td>
<td>€ 499542</td>
</tr>
</tbody>
</table>

### Extracts from the Table:

- **Average Savings per 100 Lift-Trucks:** €181,156 Euro
- **Main Target Countries:**
  - Belgium: €201,185 Euro
  - Denmark: €279,554 Euro
  - Finland: €142,962 Euro
  - Germany: €251,862 Euro
  - Italy: €198,546 Euro

---

Tampere University of Technology  
RFIC Laboratory, Department of Electronics and Communications Engineering  
Prof. Nikolay T. Tchamov  
Korkeakoulunkatu-1, TH-108 33720 – Tampere, Finland  
+358-(0)-40-582-5915  
www.cs.tut.fi/tlt/rfasic  
nikolay@cs.tut.fi  
Nov-2013
The Slow and Fast Energy Loops (1/2)

ADVANCED: 80% Energy Recovery by 1,000 Battery Cycles VERSUS 1,000,000 SuperCap Cycles

Energy taken from Battery
Energy Restored to Battery

Energy taken from SuperCap
Energy Restored to SuperCap

Tampere University of Technology
RFIC Laboratory, Department of Electronics
and Communications Engineering

Prof. Nikolay T. Tchamov
Korkeakoulunkatu-1, TH-108
33720 – Tampere, Finland
+358-(0)40-582-5915
www.cs.tut.fi/tlt/rfasic

Page 6 / 8

Nov-2013

nikolay@cs.tut.fi
The **Super-Battery** Project

**Main Applications:** City-eBusses; Fork-Lifts, Tools, UPS

### Standard Battery

- **3,000 €**
- **Battery:** 48V 200Ah
- **I/O for 2,000 Cycles**
- **For 100% Charge:** $\eta = 70\%$
  - 35 A, 8 hours
- **For 100% To Load:** $\eta = 65\%$
  - 400 A, 20 min
- **For 100% Return:** $\eta = 30\%$
  - 200 A, 320 min

### Super Battery

- **5,500 €**
- **I/O for 800,000 Cycles**
- **For 100% Charge:** $\eta = 80\%$
  - 3000 A for only 6 sec
- **For 100% To Load:** $\eta = 80\%$
  - 400 A, 45 sec
- **For 100% Return:** $\eta = 80\%$
  - 3000 A for only 6 sec

---

**RF-DCDC Converters**

- 48V 3000A

**Super-Capacitor**

- 48V 50Ah

**Cell Balancers**

- 20 Ah

---

**Tampere University of Technology**
**RFIC Laboratory, Department of Electronics and Communications Engineering**

**Prof. Nikolay T. Tchamov**
Korkeakoulunkatu-1, TH-108
33720 – Tampere, **Finland**

+358-(0)40-582-5915
www.cs.tut.fi/tlt/rfasic

**Page 7 / 8**

**Nov-2013**

**nikolay@cs.tut.fi**
The **Fastest** Implementation is to **Modify the Battery Pack Contents**

**The STRATEGY:**

1. When the Energy is *mostly used for Lifting-up*, the Battery limits the Energy Recovery below 20%.
2. Replacing 25% of Battery-Cells by SuperCap-Cells allows up to **80% Energy Recovery**.
3. The Break-through is due to a **Novel HF-DCDC** developed to be inserted with **SuperCap Cells** in the Battery Pack.
4. No Modifications are needed in Lift-Trucks and Chargers. HF-DCDC & Super-Cap can be installed by those who:
   - Manufacture Lift-Trucks
   - Sells Lift-Trucks
   - Maintains Lift-Trucks
   - Uses Lift-Trucks
   - Manufactures or/and Assembles Power Batteries
5. Associated Costs:
   - SuperCap-Cells cost $2x$ removed LeadAcid-Cells.
   - HF-DCDC cost is below 600,- €

---

**The Standard Battery Pack Contents:**

Example price 4000,- €

**The NEW Battery Pack Contents:**

Example price 5600,- €