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)

**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 nikolay@cs.tut.fi
25-Nov-2013
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,
RFIC-Lab Background, Works & Targets

Devices Modeling in CMOS, SiGe/BiCMOS

Nonlinear Electronic Circuits Theory & CAD

Novel GHz Circuits Architectures

On-Wafer RF Measurements

VCO & DCO for Mobile Terminals since 1995 ...

GHz Sampling Circuits since 1997

LNA and Filters for DVB-IC since 2003 ...

DC-DC for PA Modulation since 2006 ...

Battery & SuperCap Management ICs since 2007 ...

Low-Voltage and High-Power DC-DC since 2009 ...

Kinetic Energy Recovery Systems since 2011 ...

Wireless & PLC in High EMI since 2012 ...

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

Prof. Nikolay T. Tchemov
Korkeakoulunkatu-1, TH-10833720 – Tampere, Finland
+358-(0)40-582-5915
www.cs.tut.fi/tlt/rfasic

Page 3 / 12
25-Nov-2013

nikolay@cs.tut.fi
Mobile 48 Volt Technology Business

**Target # 1**
Fork-Lifts

**Target # 2**
Start-Stop Starter-Alternator

**Target # 3**
eBikes

### Charging from Grid

- **15 kW HF AC/DC**
- N x 15 kW Grid Chargers

### 6...15 kW Energy Recovery System

- 15 kW Hybrid BMS
- 100 Wh SuperCap Pack
- 15 kWh Battery Pack
- 15 kW HF DC/DC

### 1...3 kW Energy Recovery System

- 3 kW HF DC/DC
- 3 kW HF AC/DC
- 5 Wh SuperCap Pack
- Monolithic BMS
- 0.5 kWh Battery Pack
- 3 kW Hybrid BMS
- 3 kW HF Pack
- 15 kWh Battery Pack

---

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

nikolay@cs.tut.fi

25-Nov-2013
Page 4 / 12
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)
36 kWh Lead Acid, 48 V
24 hours/day,
2 packs/day
250 days/year
18,000 kWh/year

200 V --- Voltage --- 48 V!
People --- Transport --- Materials
Many --- Restrictions --- Few

'16' = '1'

When? --- Needed --- Now!
Japanese --- Maker --- Who?
### Worldwide lift truck market

<table>
<thead>
<tr>
<th>Region</th>
<th>2009 Orders</th>
<th>2010 Orders</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>60%</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>32%</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>45%</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, Tukk</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>Anhui Forklift Group</td>
<td>11</td>
<td>$747 million</td>
<td>Not available in North America</td>
<td>Hetai, Anhui, China</td>
</tr>
<tr>
<td>11</td>
<td>Nippon Yusiki Co.</td>
<td>12</td>
<td>$570 million</td>
<td>Clark</td>
<td>Seoul, South Korea</td>
</tr>
<tr>
<td>12</td>
<td>Clark Material Handling</td>
<td>13</td>
<td>$475 million</td>
<td>Doosan Infracore</td>
<td>Seoul, South Korea</td>
</tr>
<tr>
<td>13</td>
<td>Doosan Infracore</td>
<td>14</td>
<td>$313 million**</td>
<td>HC</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>Tailift</td>
<td>16</td>
<td>$125 million**</td>
<td>Tailift, World Lift</td>
<td>Taichung, Taiwan</td>
</tr>
<tr>
<td>16</td>
<td>Combilift</td>
<td>17</td>
<td>$110 million</td>
<td>Combilift</td>
<td>Monaghan, Ireland</td>
</tr>
<tr>
<td>17</td>
<td>Hubtex</td>
<td>18</td>
<td>$75 million**</td>
<td>Hubtex</td>
<td>Fulda, Germany</td>
</tr>
<tr>
<td>18</td>
<td>Hytstx</td>
<td>19</td>
<td>$69 million</td>
<td>Hytstx</td>
<td>Shanghai, China</td>
</tr>
<tr>
<td>19</td>
<td>Godrej &amp; Boyce Manufacturing</td>
<td>20</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.
**Figure based on industry estimate.

---

**EV Battery Market: Demand by Vehicle Type (World), 2009**

- Forklift: 23.6%
- Golfcart: 63.2%
- CEV: 1.6%
- NEV: 0.7%
- HPEV: 4.2%
- Others: 33.0%

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

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

- North America: 34.1%
- Europe: 24.9%
- Asia Pacific: 3.7%
- Latin America: 4.3%
- Rest-of-World: 23.6%

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

---

Fork-Lift-Market and related Battery-Market
## Financial Impact: Energy Recovery in Fork-Lifts

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

<table>
<thead>
<tr>
<th>Cost of the Electricity</th>
<th><a href="http://en.wikipedia.org/wiki/Electricity_pricing">http://en.wikipedia.org/wiki/Electricity_pricing</a></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Belgium</td>
</tr>
<tr>
<td>€/kWh</td>
<td>0.2235</td>
</tr>
<tr>
<td>Per Day</td>
<td>€</td>
</tr>
<tr>
<td>Per Year</td>
<td>€</td>
</tr>
</tbody>
</table>

**Charger Efficiency:** (usually 70-90)%
**Battery Efficiency:** (usually 50-65)%

**Total Battery Charging Efficiency:** 60%

**The COST of the ELECTRICITY**
- **1x LiftTruck:**
  - Per Year: €3353, €2337, €4198, €3276, €3122, €3127, €2537, €1300, €3,019
  - Lift-Trucks: €335308, €238299, €419769, €327577, €312231, €312692, €253731, €130039, €301,927
  - Lift-Trucks: €1005923, €714808, €1259308, €982731, €936926, €938077, €761192, €390115, €905,781

**Today's Energy Recovery:** 20%

| Savings for 100 Lift-Trucks | €67082 | €93185 | €47554 | €44748 | €83954 | €65515 | €62446 | €62538 | €57468 | €26008 | €60,385 |
| Savings for 300 Lift-Trucks | €201185 | €129542 | €142952 | €134236 | €251862 | €196548 | €187338 | €187615 | €152238 | €78023 | €181,156 |

**Target Energy Recovery:** 80%

| Savings for 100 Lift-Trucks | €268248 | €372738 | €190615 | €179865 | €335815 | €282062 | €248795 | €250154 | €202985 | €104031 | €241,542 |
| Savings for 300 Lift-Trucks | €804738 | €1181215 | €57846 | €536954 | €1007446 | €786187 | €749354 | €750462 | €608954 | €312092 | €724,625 |

<table>
<thead>
<tr>
<th>Then the Difference</th>
<th>20%</th>
<th>80%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Savings for 100 Lift-Trucks</td>
<td>€201185</td>
<td>€279554</td>
</tr>
<tr>
<td>Savings for 300 Lift-Trucks</td>
<td>€603554</td>
<td>€838662</td>
</tr>
</tbody>
</table>

### Extracts from the Table:
- **Average Savings per 100 Lift-Trucks:** €181,156
- **Main Target Countries:**
  - Belgium: €201,185
  - Denmark: €279,554
  - Finland: €142,962
  - Germany: €251,862
  - Italy: €196,546

---

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

25-Nov-2013
Page 7 / 12
Target #1: Forklift Energy Efficiency Boosting in:

*Usage* 2x

*Recovery* 10x

AC Grid

75% Rectifier 90%

70% Battery 85%

85% Controller 90%

65% Motor 90%

Moving OBJECT

45% Generator 85%

75% DCDC 95%

50% SuperCap 85%

75% Battery 85%

40% Rectifier 90%

40% Battery 85%

50% SuperCap 85%

65% Rectifier 90%

65% Motor 90%

50% Controller 90%

Motor 90%

Generator 85%

Battery 85%

Moving OBJECT

To Use = 90*90*85*90 ≥ 60%

To Recover = 85*90*95*85*85 ≥ 50%

In Use = 75*85*70*65 ≤ 30%

Recovered = 45*50*75*40*50 ≤ 5%
The Slow and Fast Energy Loops (1/2)

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

Battery 48V
DC-to-DC
DC-to-AC
AC-to-DC
M/G

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
25-Nov-2013

Page 9 / 12
The **Super-Battery** Project

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

---

### 3,000 € Standard Battery

**I/O for 2,000 Cycles**

<table>
<thead>
<tr>
<th>Charge</th>
<th>Return</th>
</tr>
</thead>
<tbody>
<tr>
<td>35 A 8 hours</td>
<td>200 A 320 min</td>
</tr>
</tbody>
</table>

- **400 A** 20 min
- **η** = 70%

---

### 5,500 € Super Battery

**I/O for 800,000 Cycles**

<table>
<thead>
<tr>
<th>To Load</th>
<th>Return</th>
</tr>
</thead>
<tbody>
<tr>
<td>400 A 45 sec</td>
<td>3000 A for only 6 sec</td>
</tr>
</tbody>
</table>

- **3000 A** for only 6 sec
- **η** = 80%

---

**RF-DCDC Converters**

**48V 3000A**

**Super-Capacitor**

**48 V**

**Battery**

**48V 50Ah**

**Cell Balancers**

---

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

Prof. Nikolay T. Tchamov  
Korkeakoulunkatu-1, TH-10830720 – Tampere, Finland  
+358-(0)40-582-5915  
www.cs.tut.fi/tlt/rfasic  
nikolay@cs.tut.fi

25-Nov-2013  
Page 10 / 12
Next Step: Advanced 48V Dynamic EIS and Energy Balancing

Dynamic EIS-C:
- V
- I
- T°
- Z(ω)
- Noise
- SoC
- SoH

Dynamic EIS-B:
- V
- I
- T°
- Z(ω)
- Noise
- SoC
- SoH
48V 56kW **Demonstrator:**
The SuperKart of RFIC-Lab @ ECE-TUT

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max Speed</td>
<td>280 km/h</td>
</tr>
<tr>
<td>Torque</td>
<td>528 Nm</td>
</tr>
<tr>
<td>Acceleration 100km/h</td>
<td>3.1 sec</td>
</tr>
<tr>
<td>Weight</td>
<td>230 Kg</td>
</tr>
<tr>
<td>Capacity</td>
<td>6.2 kWh</td>
</tr>
<tr>
<td>Discharge Max</td>
<td>40C Max</td>
</tr>
<tr>
<td>Charge (15min)</td>
<td>4C Max</td>
</tr>
<tr>
<td>Weight</td>
<td>60 V</td>
</tr>
<tr>
<td>Development Power</td>
<td>60 kW</td>
</tr>
<tr>
<td>Continuous Power</td>
<td>90 kW</td>
</tr>
<tr>
<td>Max. Power</td>
<td>31.4 Kg</td>
</tr>
</tbody>
</table>

Battery & SuperCap:
- Weight: 47.3 Kg
- Capacity: 6.2 kWh
- Discharge Max: 40C
- Charge (15min): 4C
- Dynamic BMS-CPU

Motor & Transmission:
- Development Voltage: 60 V
- Continuous Power: 60 kW
- Max. Power: 90 kW
- Weight: 31.4 Kg

Power-to-Weight Ratio: 2 : 1