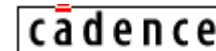


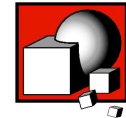
DETAILS

HF Design Technologie für präzise analoge IP-basierte Front-End Lösungen in
höchstintegrierten Datenübertragungs-Systemen

NOKIA



CST



Kooperationsworkshop Prozeßschwankungen

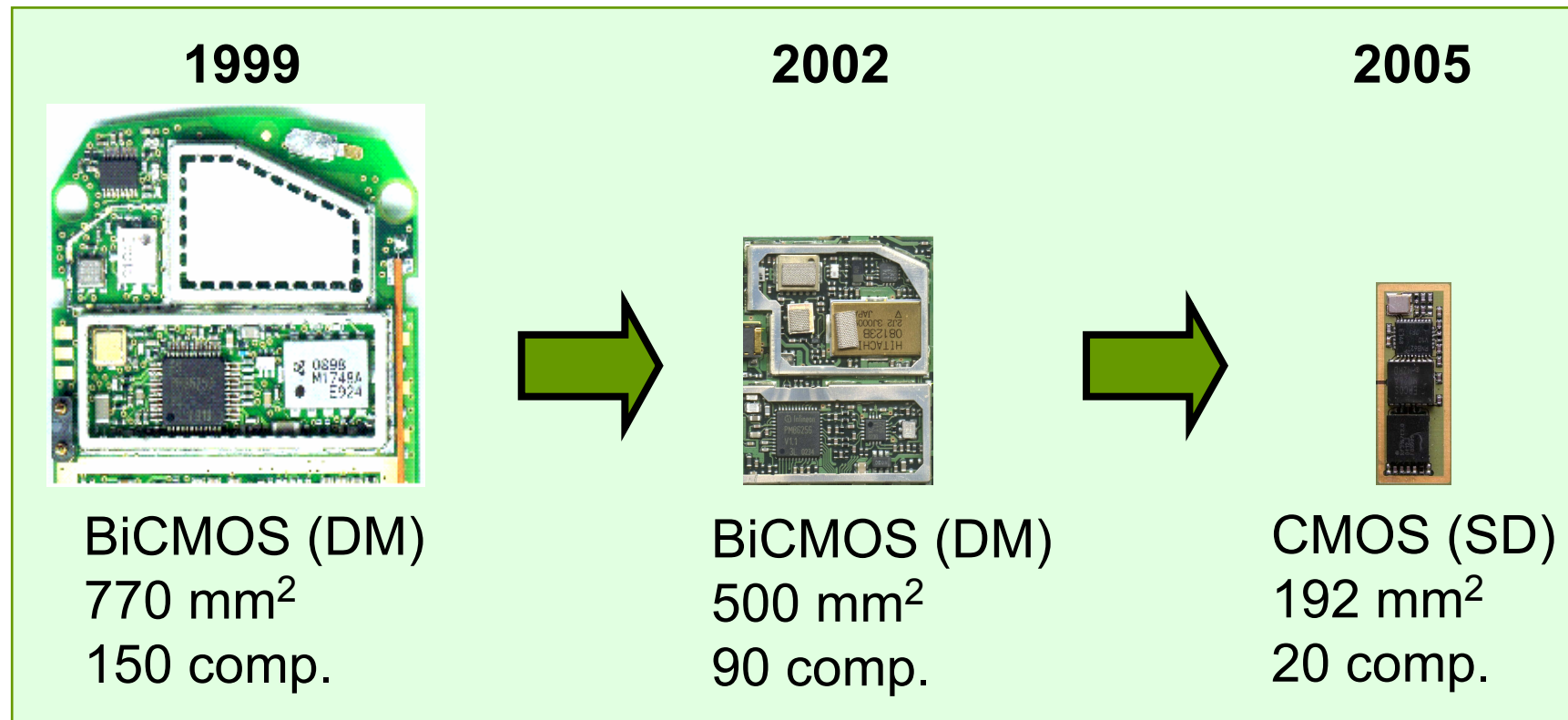
Reduction of PLL Loop Gain Variations by Digital Calibration

Christian Munker
Infineon Technologies AG

- Motivation for CMOS RF
- Sigma-Delta Modulation Transmit Architecture
- Calibration of VCO Center Frequency (BABS)
- Calibration of PLL Loop Gain (OLGA)
- Conclusion and Outlook

Motivation for CMOS RF (1)

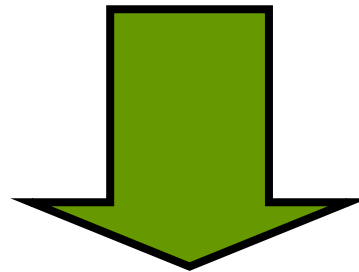
Development of IFX RF subsystem (GPRS / EDGE)



Trend: Low cost, small form factor, more features

CMOS

- Lower costs
- Better shrink potential
- Better integration capabilities
- More signal processing possibilities



CMOS is becoming THE mainstream RF technology!

Pros and Cons of CMOS RF

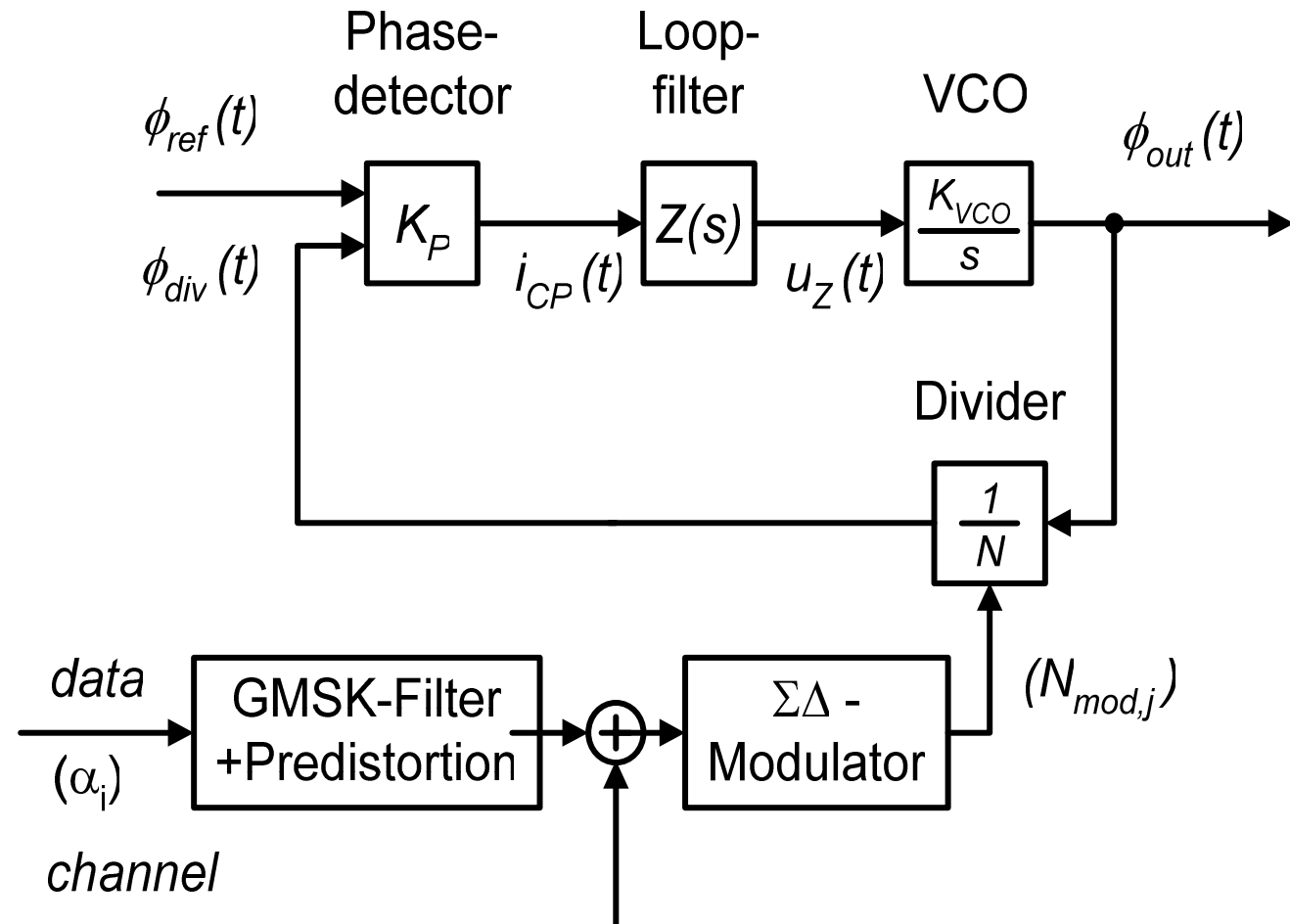
- + Fast enough for most RF applications
- + Reaches technology nodes ~18 months earlier than BiCMOS
- + Higher degree of integration possible
- Worse flicker noise and parameter spread
- Low g_m / I ratio

⇒ **New architectures** utilizing DSP are needed to compensate parameter spread of CMOS!

Sigma-Delta Modulation Transmit Architecture



- mainly digital architecture
- no mixer required
- robust against PA leakage
- bandwidth extension by predistortion

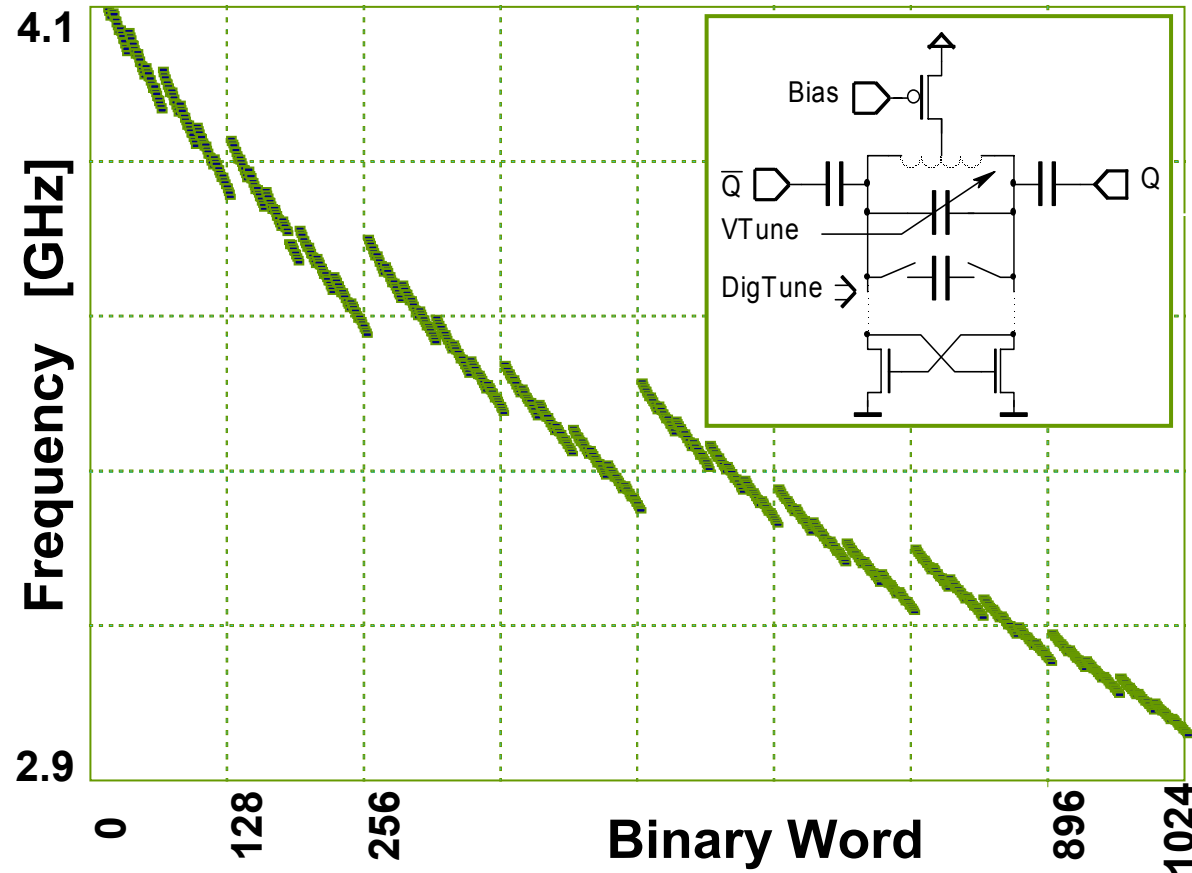


Challenges of CMOS SD Modulation Transmitter

- **Wide VCO tuning range** to compensate for process variations
- **Low, well controlled VCO gain** to reduce noise contribution
 - ⇒ **Binary Auto Band Selection (BABS)**
- **Precise matching** of digital predistortion and analog loop characteristic required (max. $\pm 10\%$ deviation) to achieve RMS phase error below 5°
 - ⇒ **Open Loop Gain Auto Adjustment (OLGA)**

VCO with 10 Bit Digital Band Selection

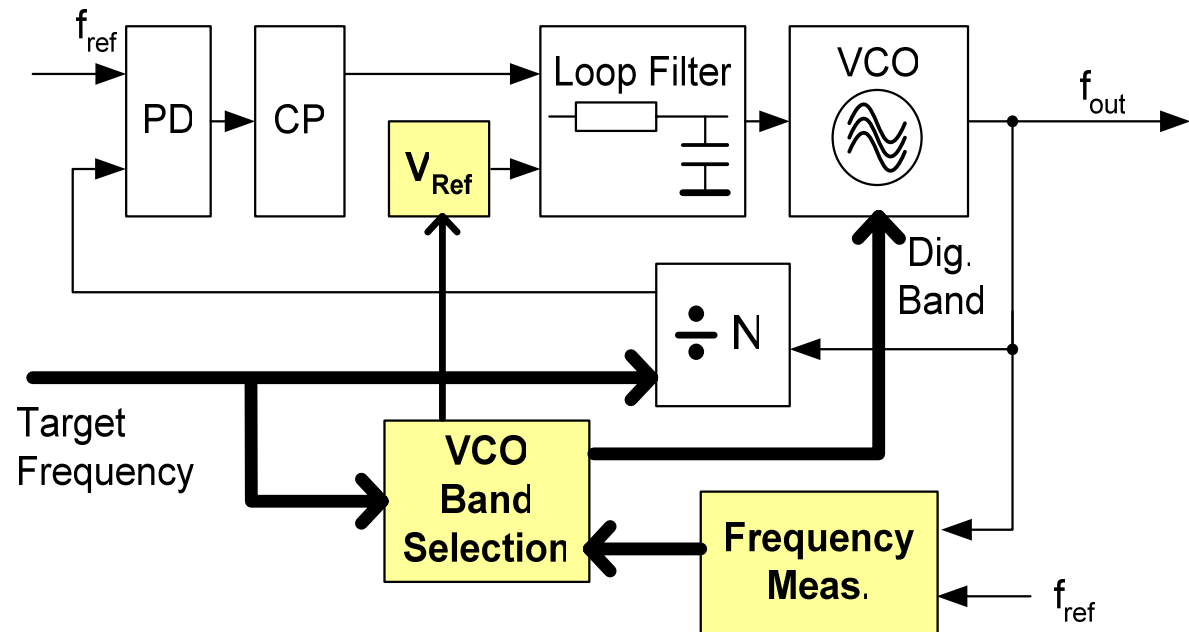
- **MOS** tuning elements
- Tuning range: **1200 MHz**
- VCO Gain **60 MHz/V**
± 10%



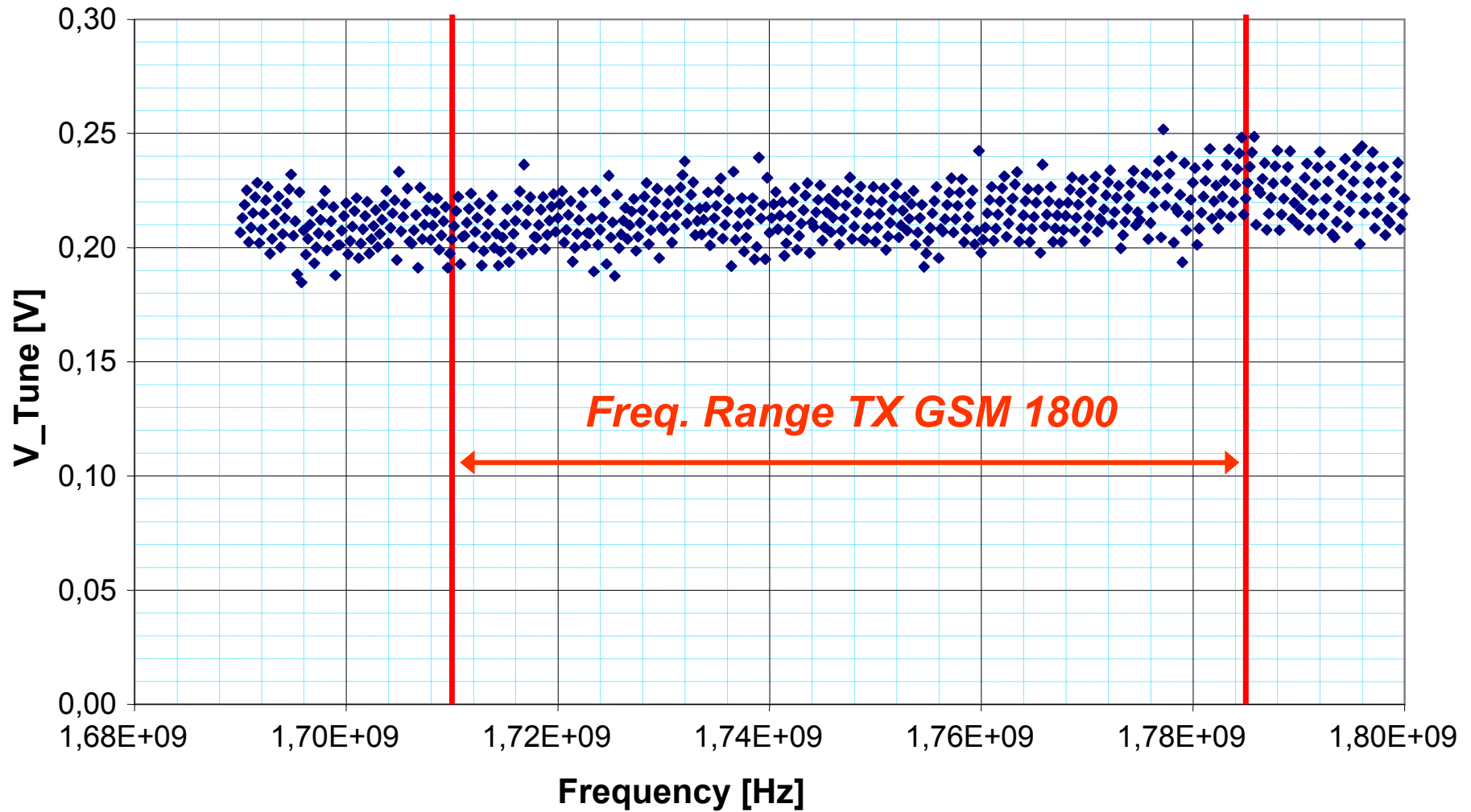
- ⇒ Large tuning range with digital band selection
- ⇒ Low, well-defined VCO gain for analog tuning

Binary Auto-Band Selection (BABS)

- Successive approximation selects VCO band closest to target frequency
- Remaining frequency error is corrected by analog tuning
- Overlap between bands required for modulation and mismatch



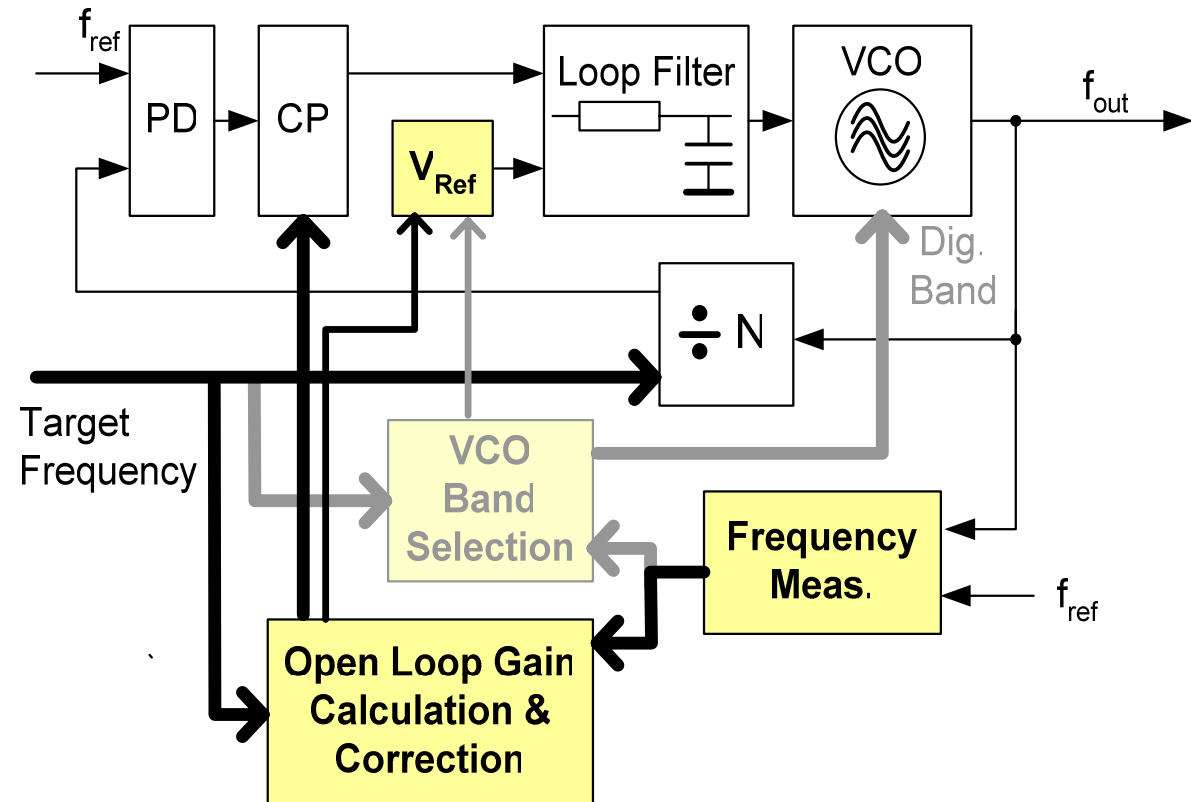
Tuning Voltage Over Frequency after BABS



Open-Loop Gain Automatic Adjustment (OLGA)



- VCO gain is measured
 - CP gain is varied
 - Product of VCO and CP gain is kept constant by algorithm
- ⇒ Constant loop gain!



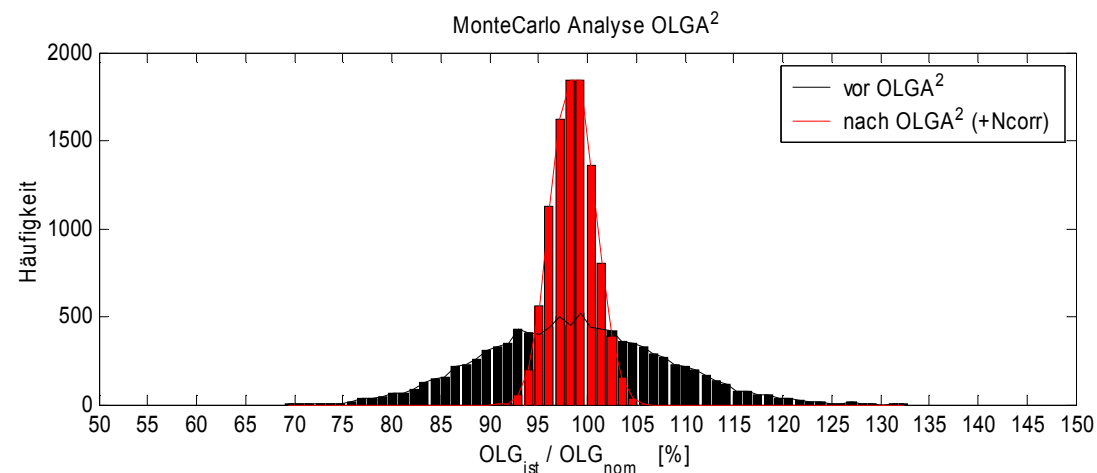
Monte Carlo Simulation of OLGA



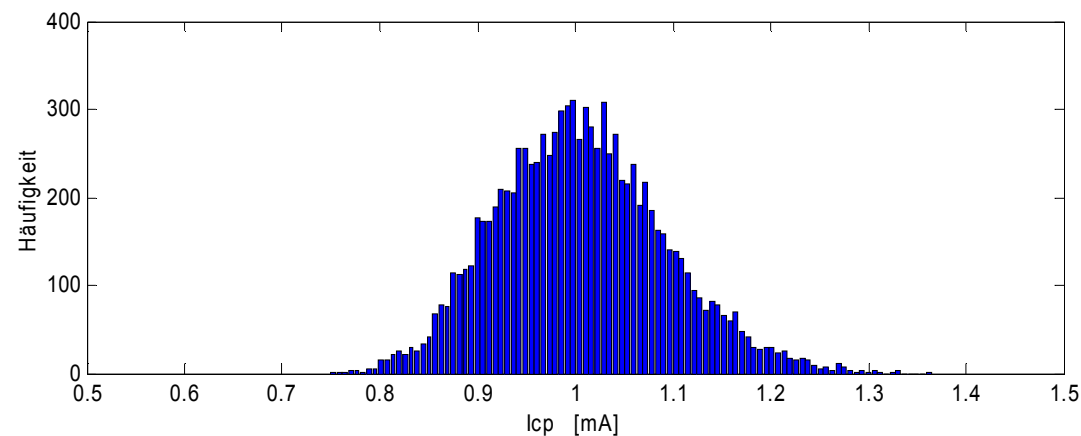
Distribution of Loop Gain:

Gain:

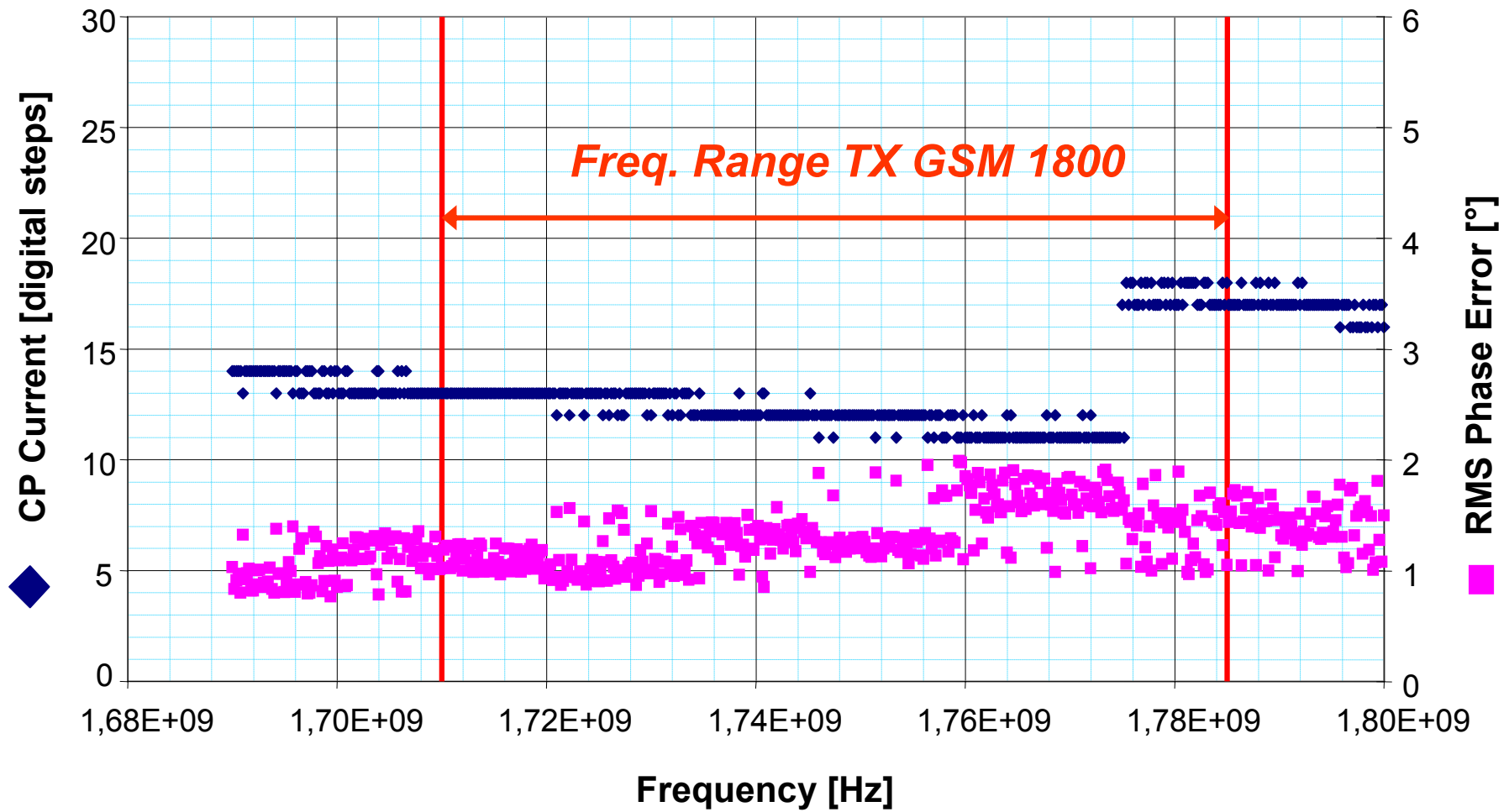
- *before* automatic calibration
- *after* automatic calibration



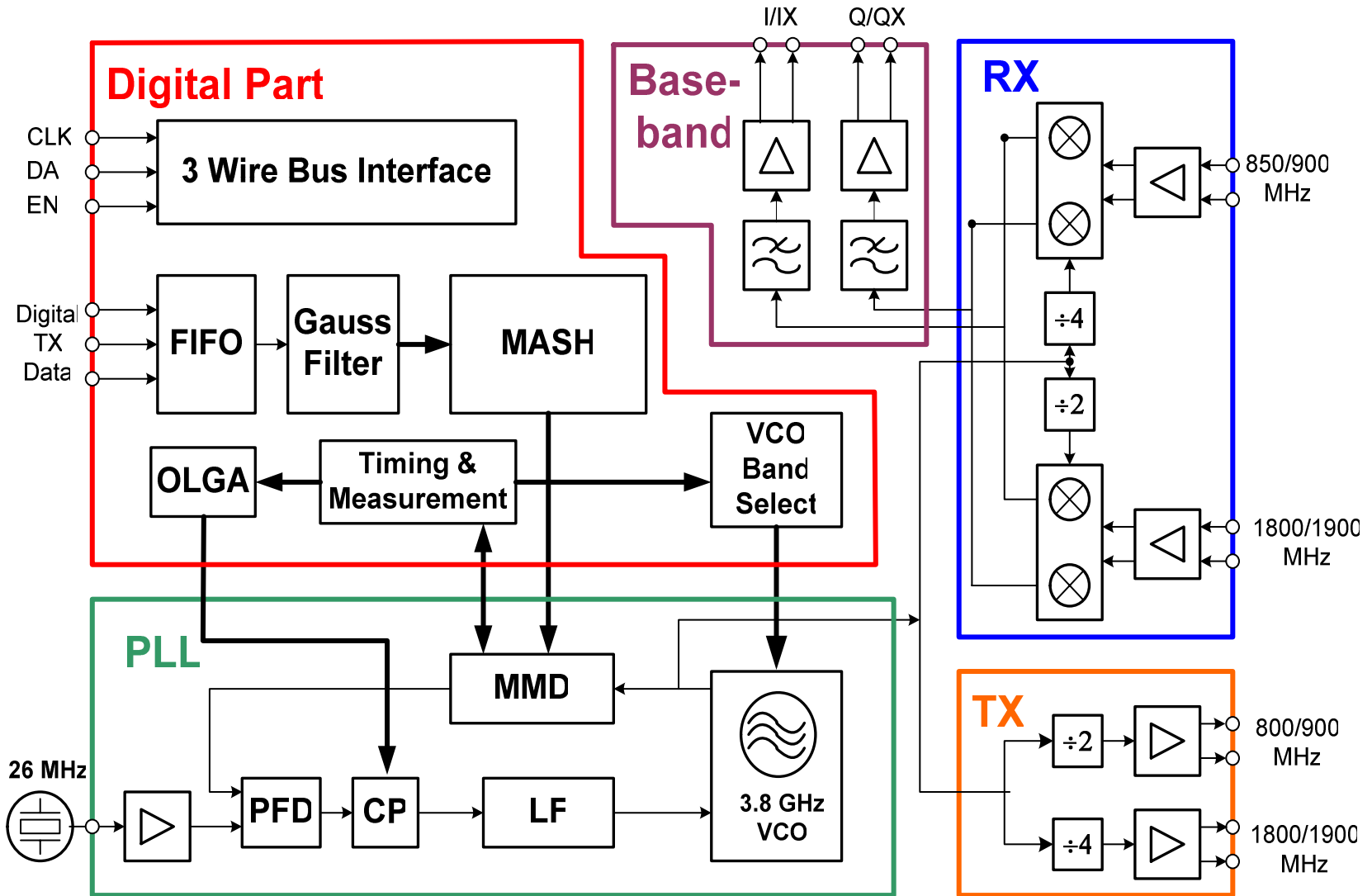
Distribution of charge pump current *after* automatic calibration reflects initial loop gain distribution



Phase Error Measurements After OLGA



GPRS Transceiver with SD-Modulator



DETAILS

- In spite of worse analog performance and parameter spread, CMOS is THE technology for consumer products
- Digital signal processing compensates for analog parameter variations of low-cost CMOS processes:
 - VCO with wide tuning range and controlled low gain
 - Calibrated PLL loop gain enables modulation bandwidth extension
- Possible future on-chip calibrations:
 - On-chip loop filter adjustment
 - RX I/Q mismatch compensation
 - ...