RF CMOS Products for Cellular Phone Applications: Challenges and Architectures

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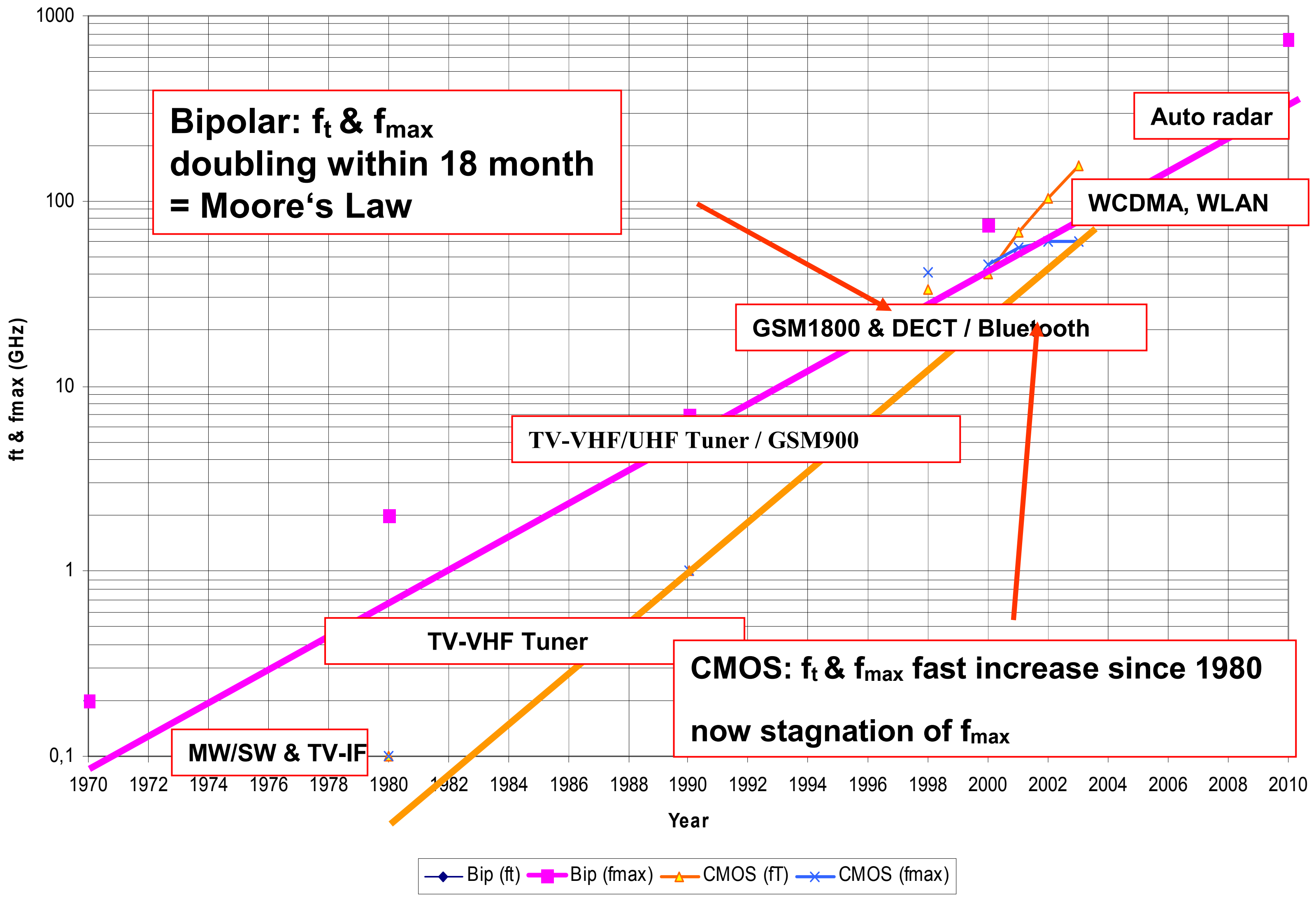
Infineon

Never stop thinking.

outline

- Overview of cellular RF markets and requirements
  - technology comparison of BiCMOS and CMOS RF
- GSM CMOS RF transceiver
  - GSM CMOS RF transmitter
  - GSM CMOS RF receiver
- Future trends

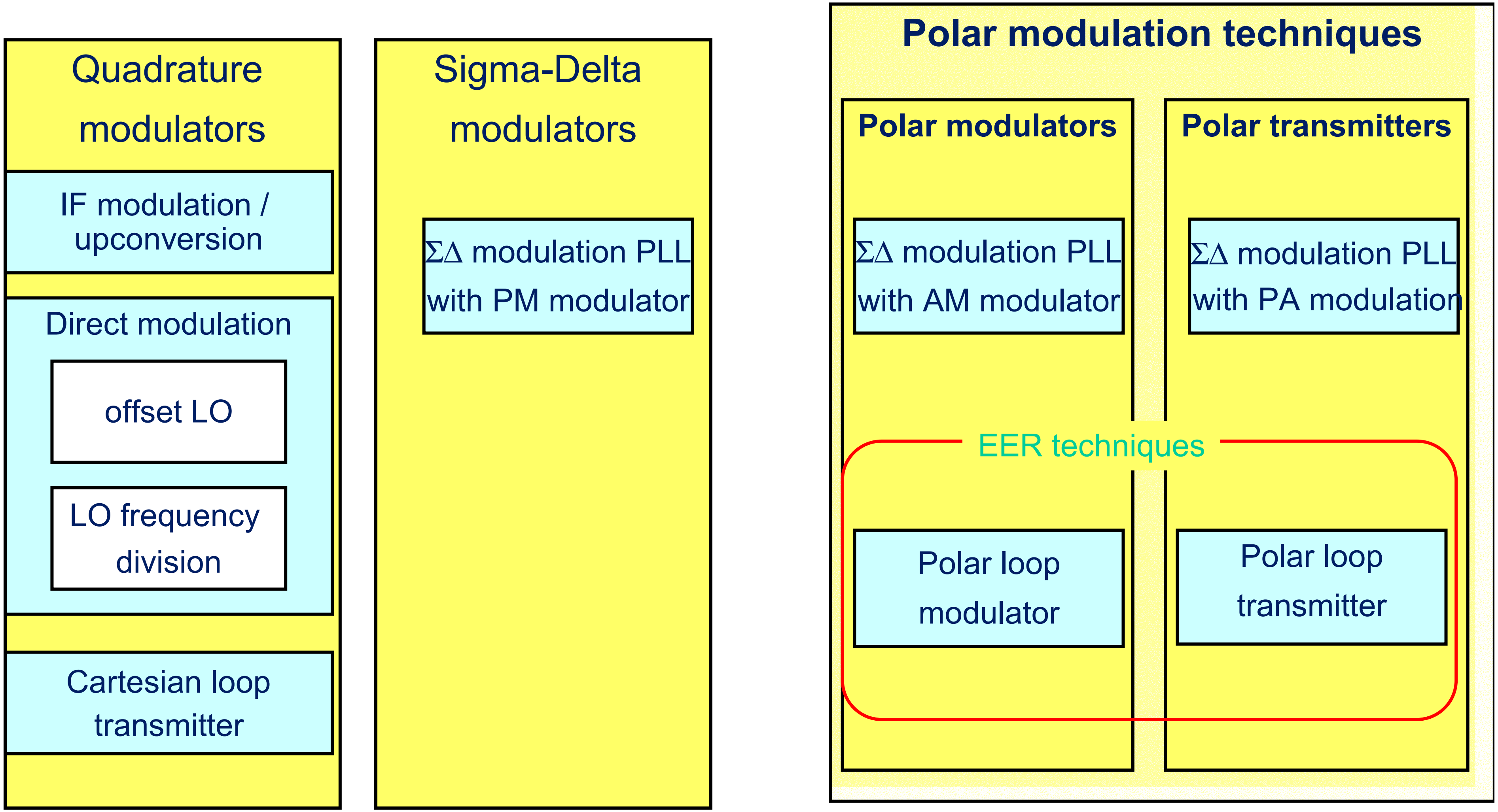
Technology progress in transit frequenz f_t and maximum frequency f_{max} as driver for RF-ICs for consumer applications on the mass market



Infineon 120nm CMOS Technology

- 120 nm RF Transistor with f_T > 100 GHz (V_{DD}=1.5V)
- Oxide thickness 2.8 nm
- 400 nm analogue I/O Transistor (V_{DD}=2.5V)
- 6 copper layers up to 550 nm thick
- MIM CAP (2 fF/um^2)
- Diffusion and Polysilicon Resistors

GSM RF Transmitter Architectures



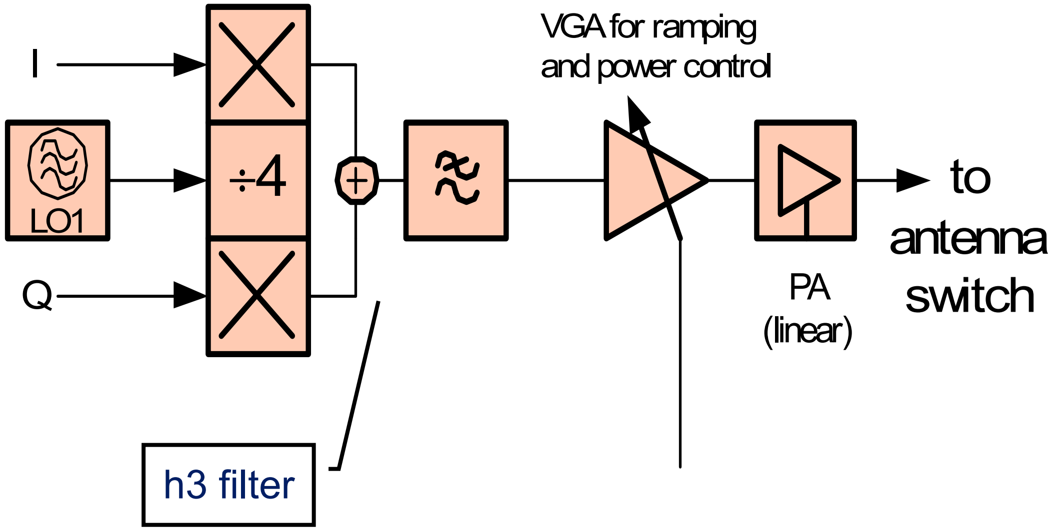
Linear Modulation Architectures

High data rates require linear modulation techniques using e.g. 8PSK, QAM 64, OFD (opposed to GMSK):

Problems of Linear Transmit Architectures

- PA Feedback to VCO: Leakage of modulated TX signal back into VCO creates sidebands
- Stringent requirements for GSM / EDGE Transmit Noise in Receive Bands:
  - GMSK: -162 dBc/Hz (20 MHz Offset)
  - 8PSK: -157dBc/Hz (20 MHz Offset)
- Each signal processing step after transmit signal generation (VCO) is extremely critical concerning noise and consumes a lot of current

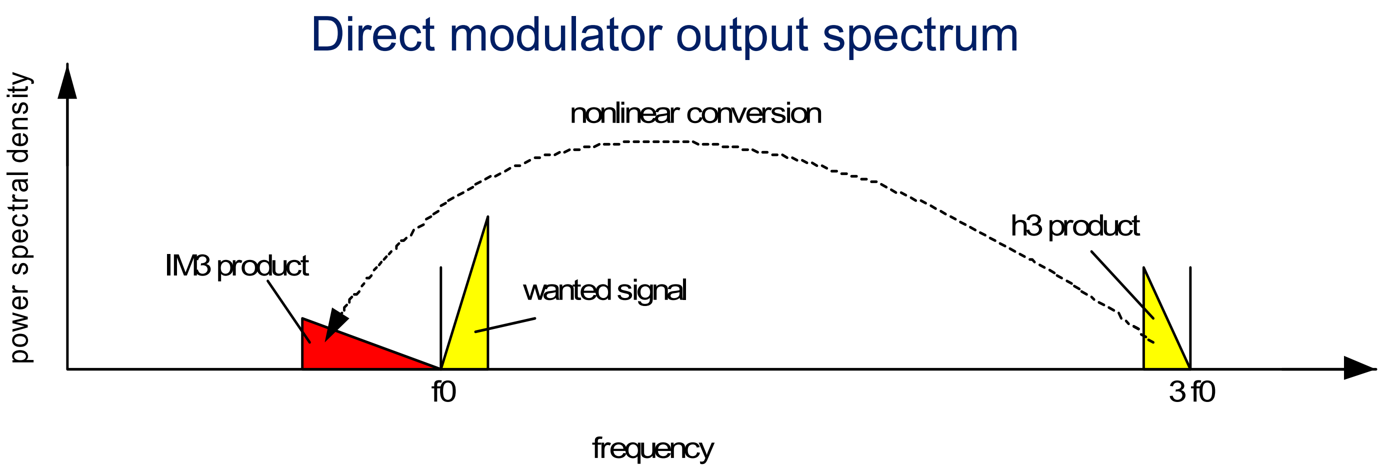
Direct modulation architecture (LO frequency division)



Direct modulation with LO division (usually by 2 or 4) is very suitable for highly integrated low cost solution:

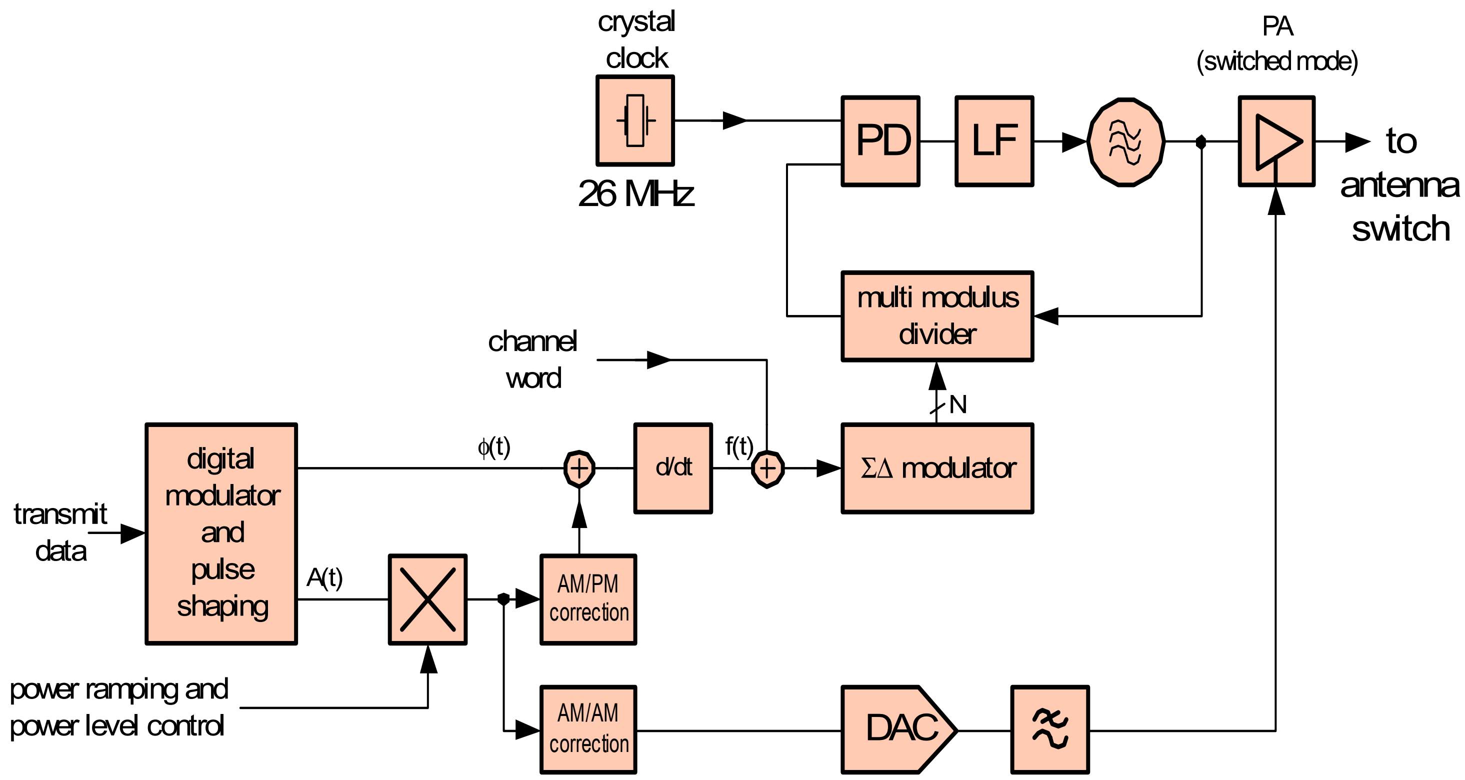
- **Provides very wide band, well defined 0/90 degree relation**
- **Only one synthesizer needed**
- **But: This concept is sensitive to PA feedback (harmonics)**

Direct modulation architecture (LO frequency division)



- Spectral regrowth due to H3 conversion

Polar transmitter



- Not seen in mass production of cellular phones so far
- Huge dynamic range for PA control (power level + modulation rang
- Matching of amplitude / phase path is essential
- AM/PM and AM/AM modelling needed over temperature / productio

Comparison of modulation techniques

	Quadrature	Sigma Delta Modulation	Polar Modulation	Polar Transmitter
preferred technology	BiCMOS	CMOS RF	CMOS RF	CMOS RF
Chip cost	high	low	low	Low
System BOM	High Filter/shield	medium	medium	Low nonlinear PA
EDGE capability	yes	No GMSK-only	yes	yes

High Performance RX Front Ends for RF in CMOS

- Direct conversion receiver is preferred architecture for both BiCMOS and CMOS GSM systems (low BOM / no SAW filters)
- Critical performance parameters for RX front ends in CMOS are
  - flicker noise
  - matching
  - low break through voltages
  - low g_m/I ratio / low driving capability
  - complicated ESD and latch up security
  - substrate crosstalk when bulk CMOS is used

- CMOS front-ends are complicated to do, but with a good system approach, design and layout very good results are achievable

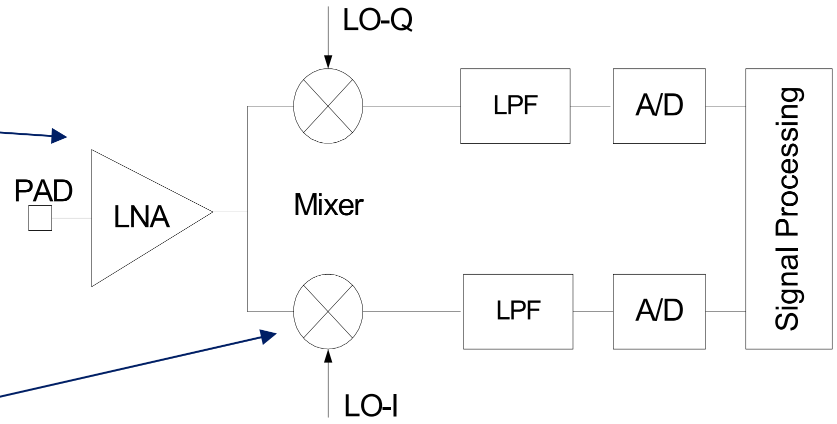
Challenges for CMOS Receivers

- Improvements of RF Receivers in CMOS processes
  - potential implementation of self alignment procedures to overcome process variation issues
  - due to high speed digital, signal processing can be done closer to the antenna, thus shrinking of RX is enabled
  - availability of very fast CMOS devices: 0.13µm f_t=100GHz

- But: remaining RF building blocks are even more challenging:
  - LNA: power gain, cross talk sensitivity and matching to 50Ohms
  - Mixer: dynamic range, driving level for switching transistors for optimum noise,
  - flicker noise optimization

Design Issues for CMOS RF Receivers

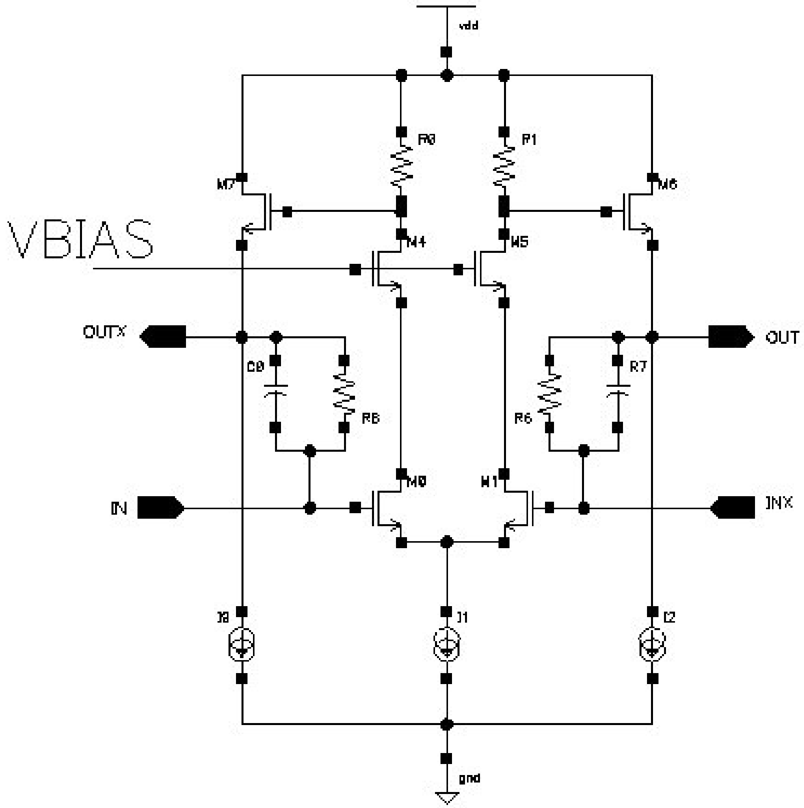
- Even in a highly digitized radio two complicated building blocks remain in the receiver
  - **LNA**
    - **power gain**
    - **noise figure**
    - **matching to 50 Ohms**
    - **ESD**



  - **Mixer**
    - **flicker noise performance**
    - **IP2**
    - **headroom with low supply voltage**

High Performance RF CMOS Receivers

- Potential solutions for LNA:
  - Trans-impedance amplifiers
    - good noise performance
    - good crosstalk performance
    - higher current consumption
    - limited headroom
    - low area consumption
  - Coil LNA´s
    - good noise performance
    - limited crosstalk performance due to inductive coupling
    - lower power consumption
    - improved linearity
    - larger die area
  - Only coil LNA achieves sufficient performance



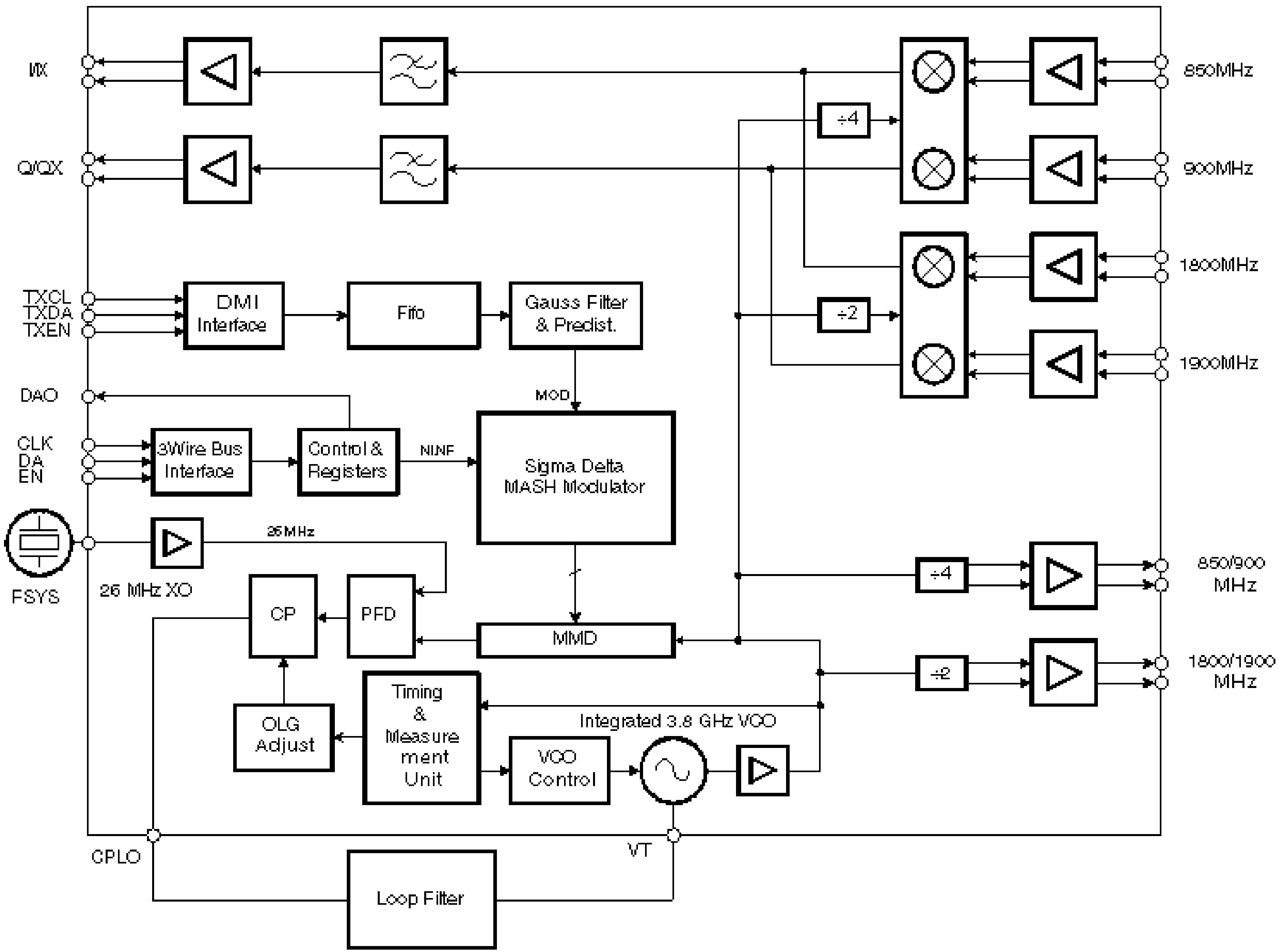
Trans-impedance amplifier

Results CMOS Sigma Delta GSM Transceiver

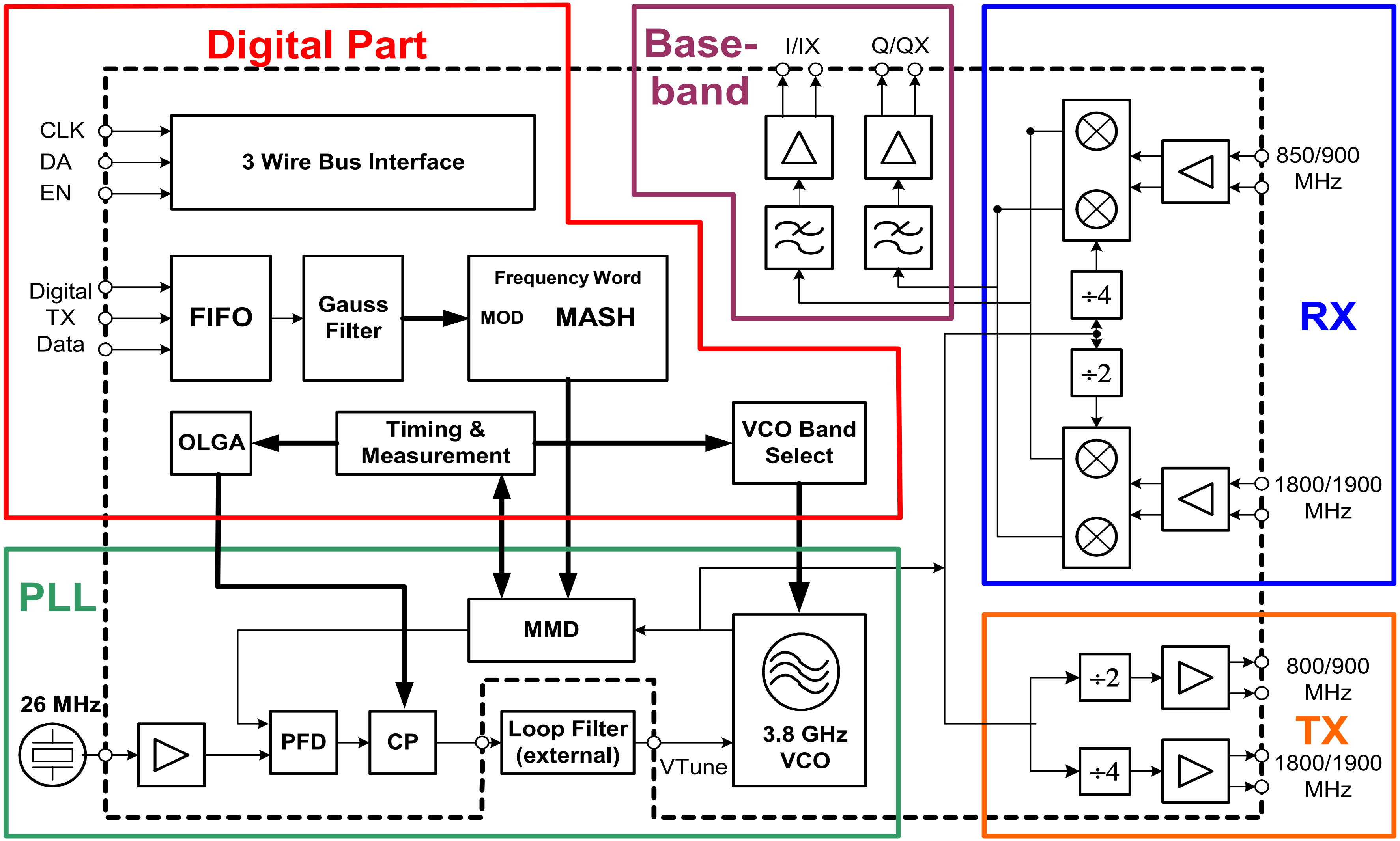
Features:

- Direct Conversion RX and TX
- Supported Bands 850/900/1800/1900 MHz
- Internal RX and TX VCO
- ΣΔ-Modulation Loop for GMSK
- Constant gain receiver for 14 bit ADC
- Part of complete GSM/GPRS Platform
- 48-pin VQFN Plastic Package

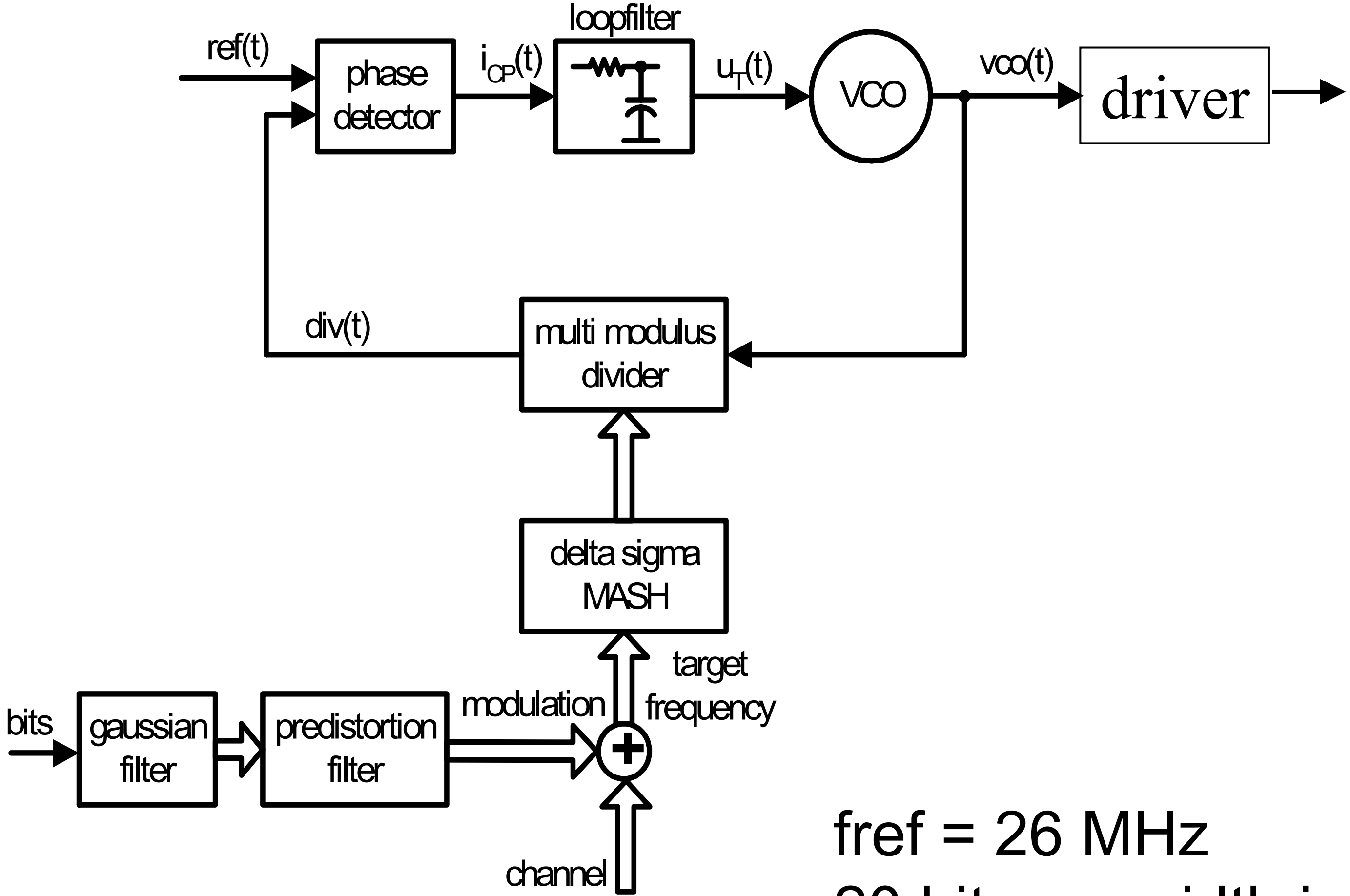
Sigma-Delta Transceiver block diagram



Sigma-Delta Transceiver block diagram



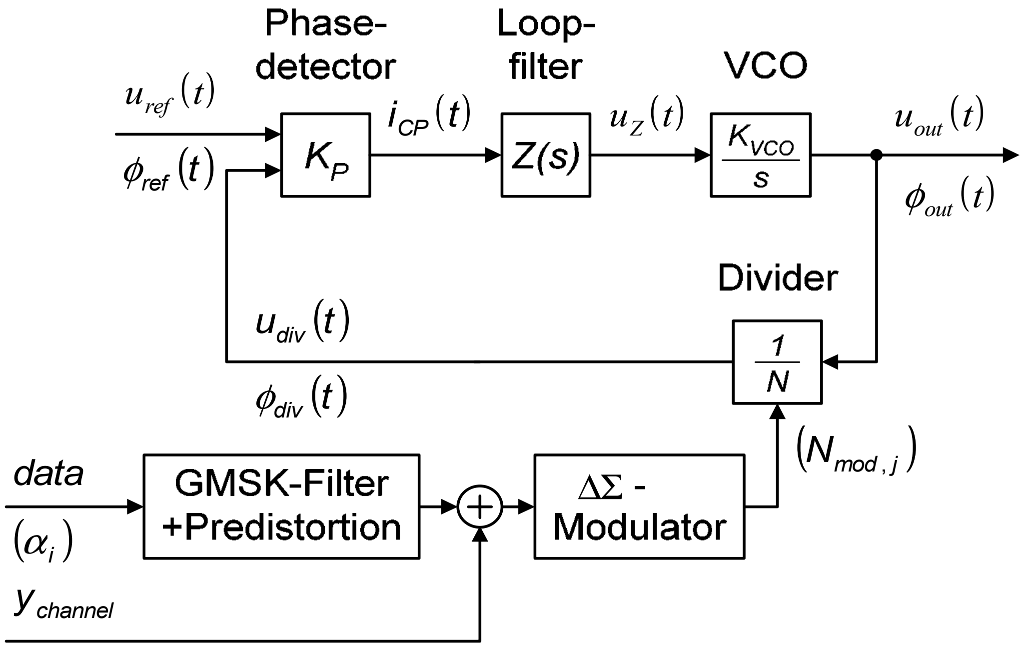
Delta-Sigma Frac.-N PLL Modulation Loop



fref = 26 MHz

20 bit accuwidth in MASH

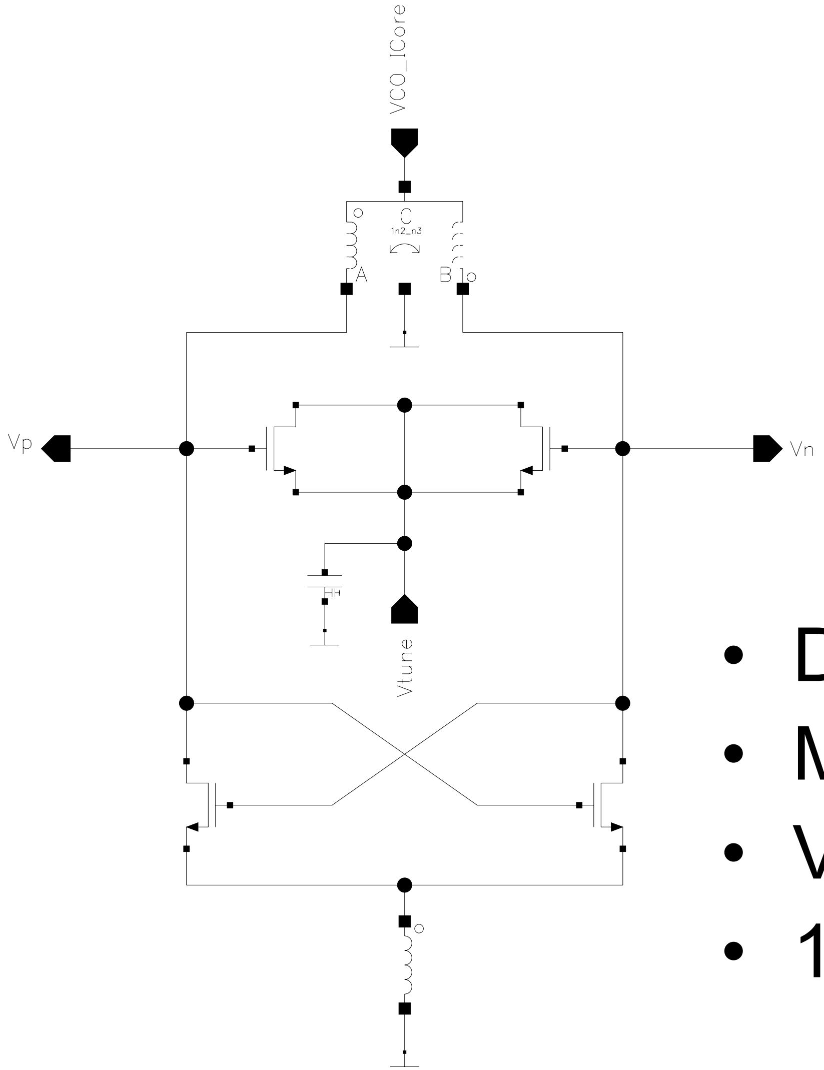
Concept of Predistortion Filter



$$\frac{\Phi_{out}(s)}{\Phi_{ref}(s)} = N \cdot \frac{1}{1 + \frac{N}{K_P K_{VCO}} \frac{s}{Z(s)}} = N \cdot G(s)$$

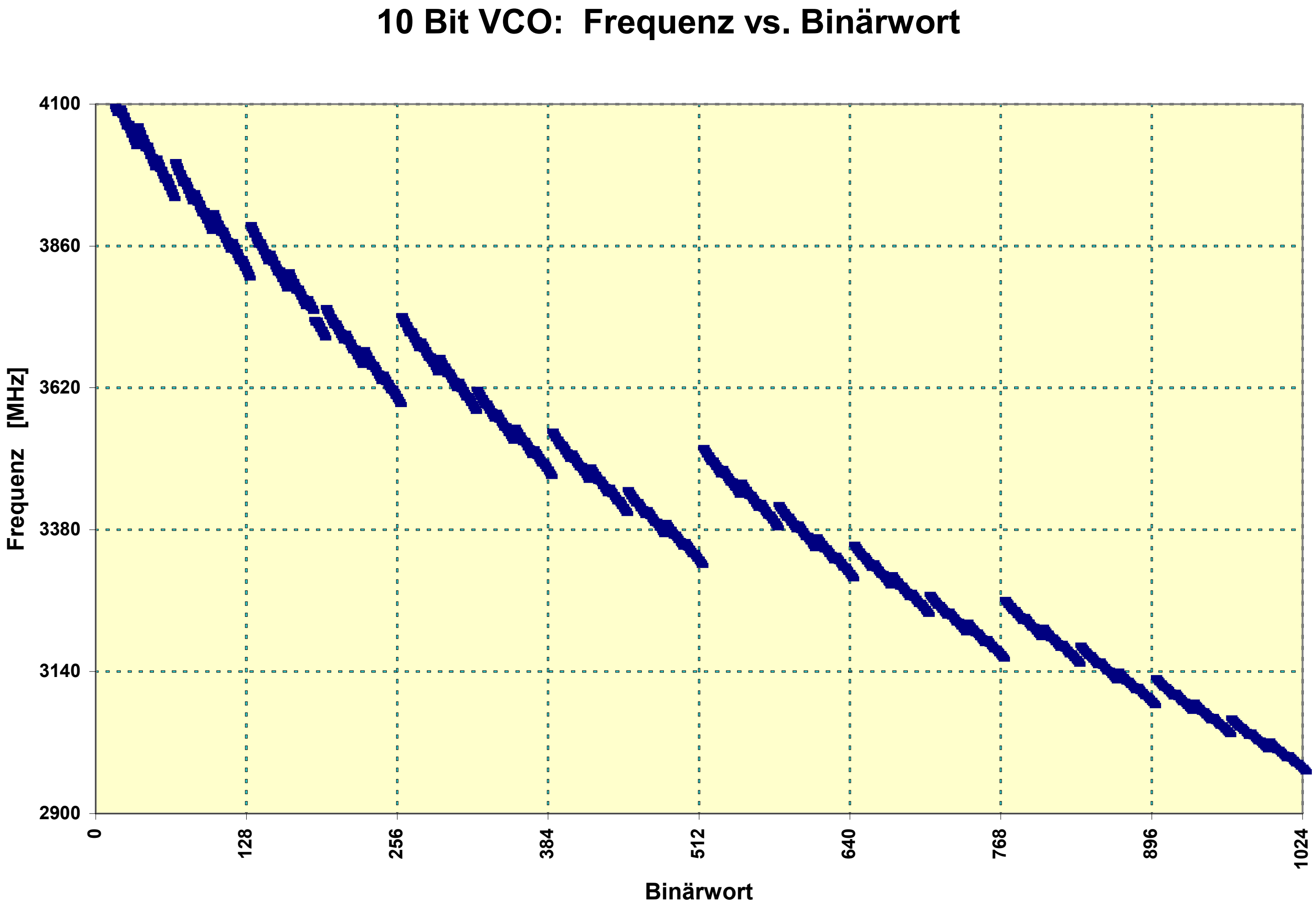
$$f_{out}(s) = N_{mod}(s) \cdot f_{ref} \cdot G(s) \cdot G(s)^{-1} = N_{mod}(s) \cdot f_{ref}$$

Voltage Controlled Oscillator Core



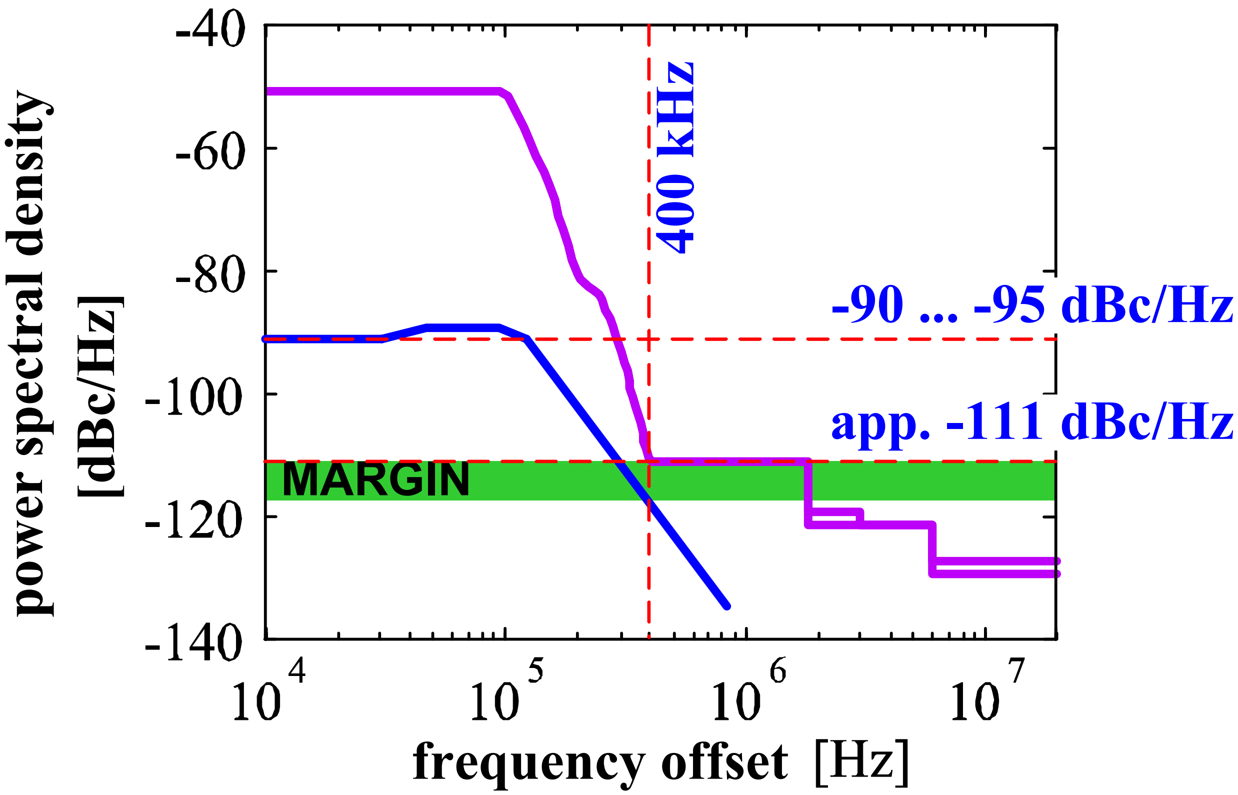
- Differential Cross Coupled
- MOS Tuning Element
- VCO gain 60 MHz +/-10%
- 1300 MHz frequency range

VCO Frequency Band Select



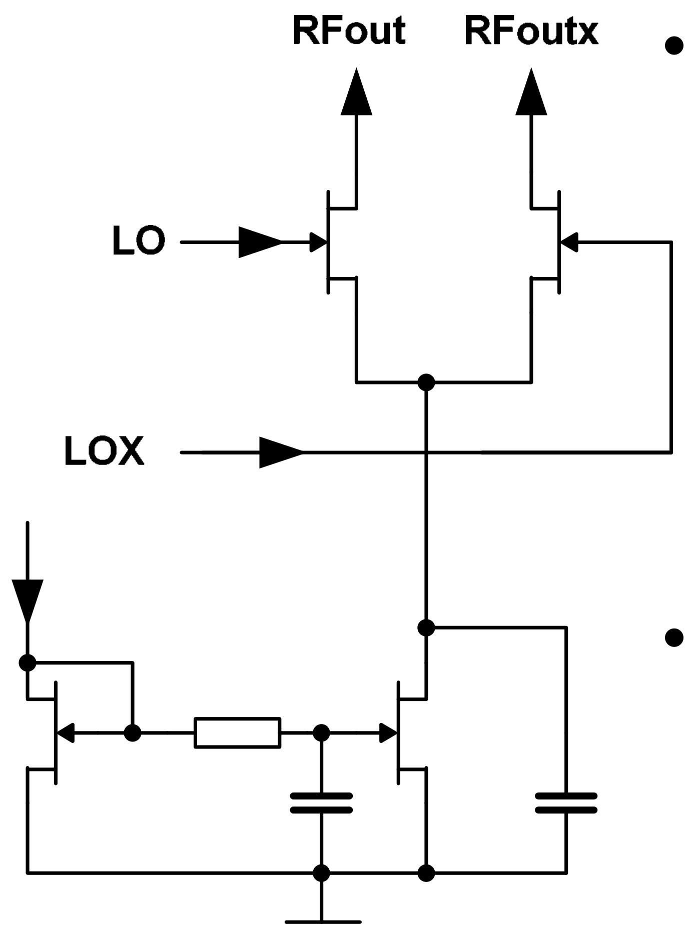
Frequency Accuracy: 2 MHz per bit

Loop Dynamic Requirements



⇒ **high loopfilter suppression needed at 400 kHz, but the modulation needs to have a wide bandwidth!**

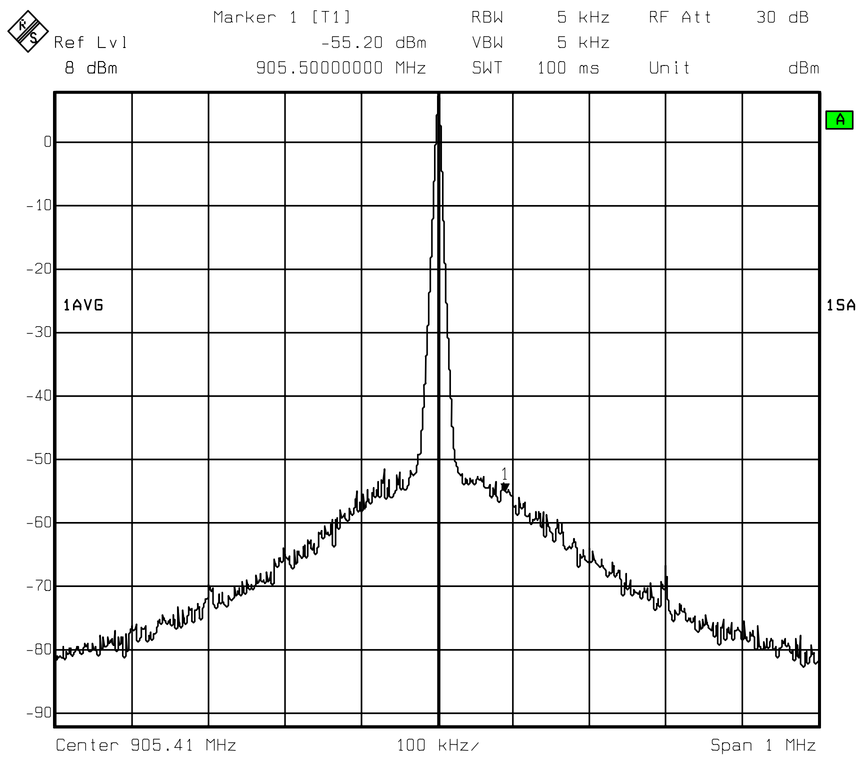
Driver Amplifier

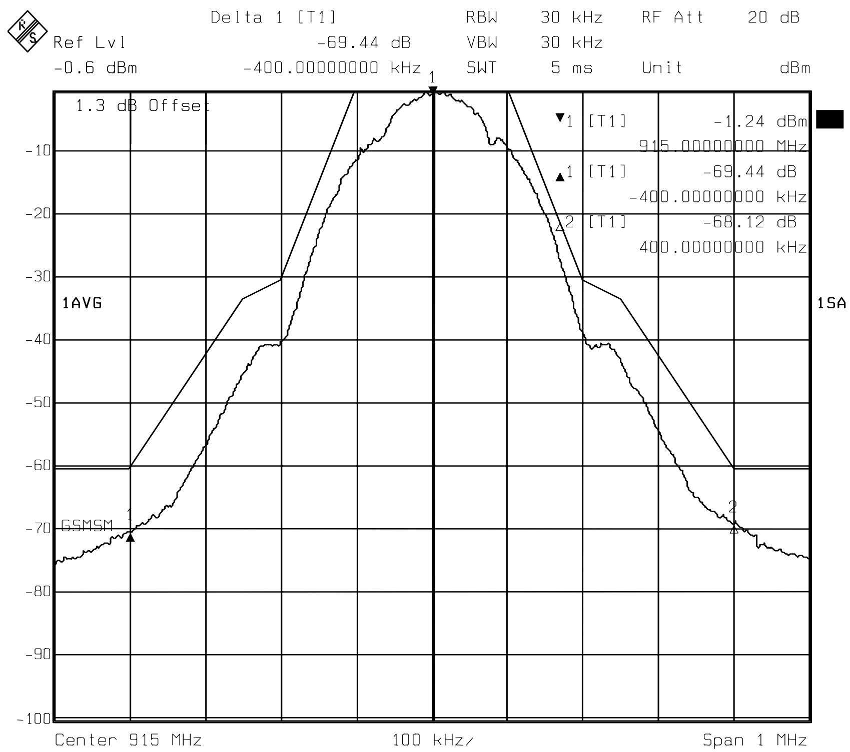


- Differential Output
  - 1.5 V Supply Voltage
  - Drives 50 Ohm Load
  - Broadband (flat over band)
  - Low Noise

- Separate 900/1800 MHz Outputs
  - 8.5 dBm @ 900 MHz
  - 8 dBm @ 1800 MHz

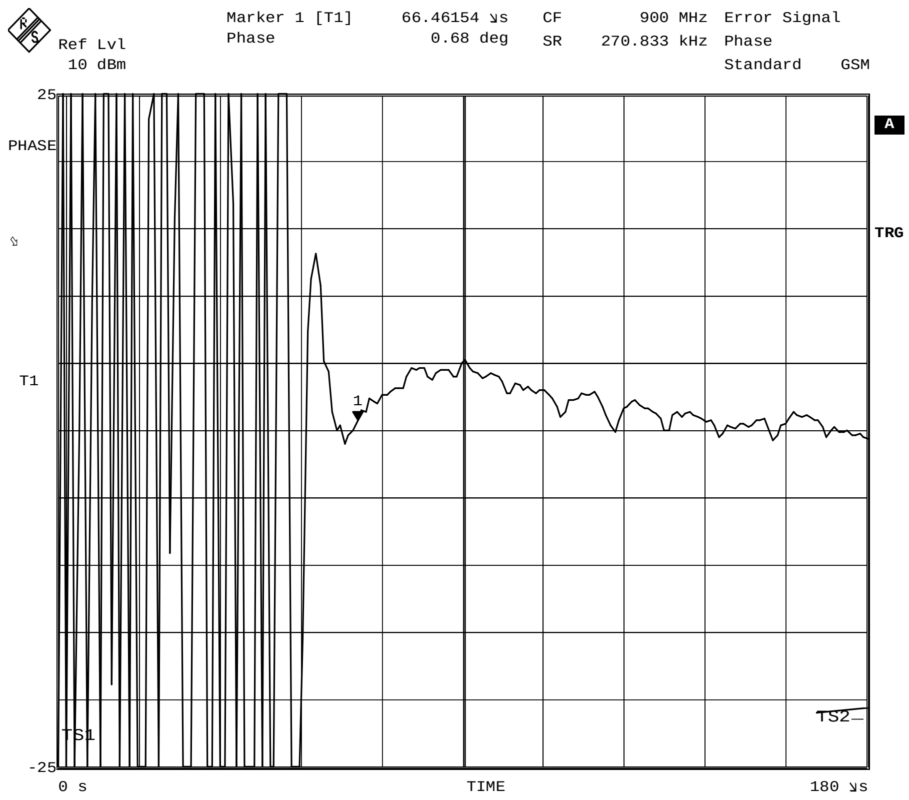
SD Modulation Spectrum





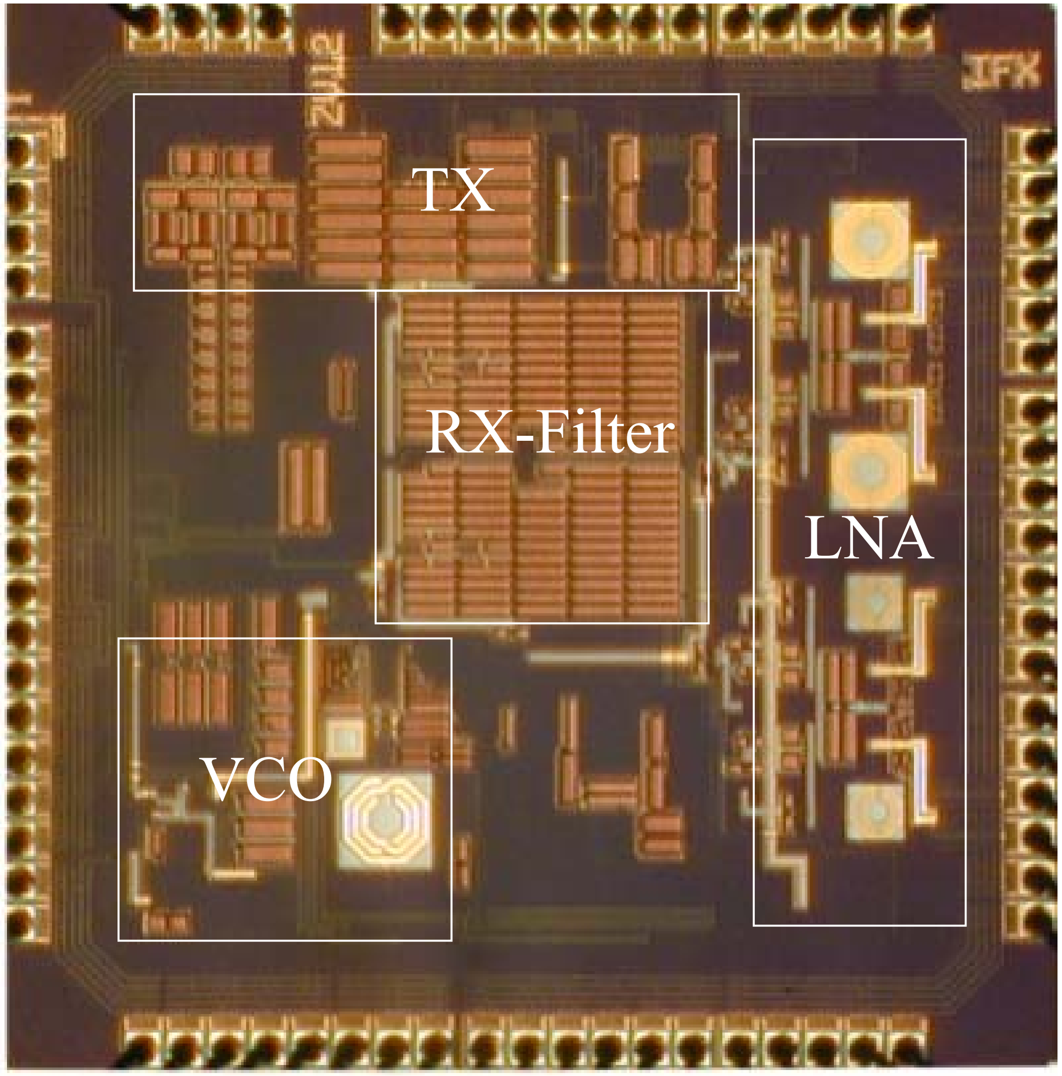
High margin to GSM Specification due to low phase noise

PLL Settling Time



analog PLL settling time < 80 µs

Chip Photograph



Performance Summary

	GSM850/GSM900	GSM1800/1900
Gain	57 dB	57 dB
Noise Figure	2.6 dB	3 dB
1 dB Compression	-22 dBm	-22 dBm
IIP2	50 dBm	50 dBm
RX Phase Noise @ 600 kHz	-129 dBc/Hz	-123 dBc/Hz
TX Phase Noise @ 40 kHz @ 20 MHz	-96 dBc/Hz < -162 dBc/Hz	-100 dBc/Hz <-157 dBc/Hz
Phase error	1.4 °	1.6 °
TX Output Power	8.5 dBm	8 dBm
Power consumption TX RX	210 mW 250 mW	

Future trends

- **Reconfigurability for Multi Mode / Multi Function Terminals**

Single chip CMOS Multiband/Multimode Transceiver

Transmit/Receive Bands:

- RX: 800 - 2200 MHz
- TX1: 776 - 958 MHz
- TX2: 1710 - 1990 MHz

Standards:

- GSM/EDGE
- UMTS
- CDMA2000/IS95