A 22mW Bluetooth RF Transceiver with Direct RF Modulation and On-chip Filtering

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Outline

- Introduction
- Transceiver architecture
- Transmitter
- Receiver
- Measurement results
- Conclusions

Bluetooth

- Cable replacement/ad hoc networking
- 2.4GHz – 2.5GHz ISM Band
- 79 channels with 1MHz spacing
- Frequency hopping at 1600hops/s
- 1Mb/s 2-level GFSK modulation
- Modulation index = 0.28 - 0.35
- Transmit power
  - +0dBm for 10m (**This work**)
  - +20dBm for 100m (Power control required)

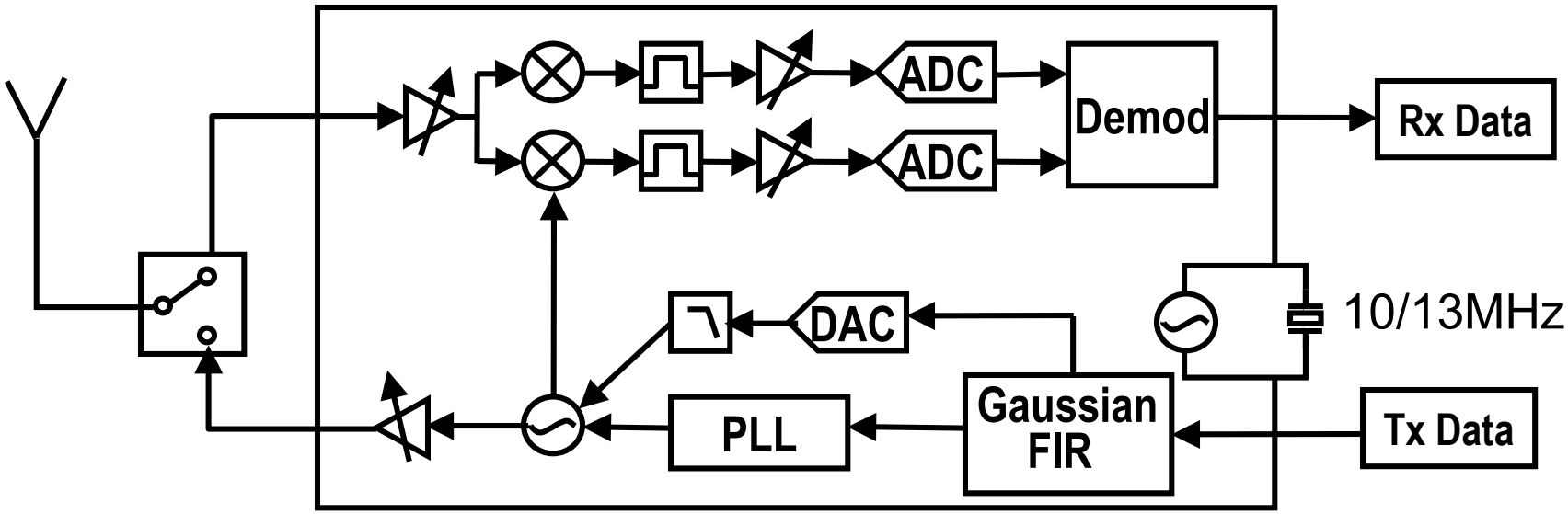
Bluetooth Applications

- Highly mobile devices are the key
  - Wireless headsets
  - Handsets
  - Personal digital assistants
  - Digital cameras
- **Lower power = longer battery life**

Goals

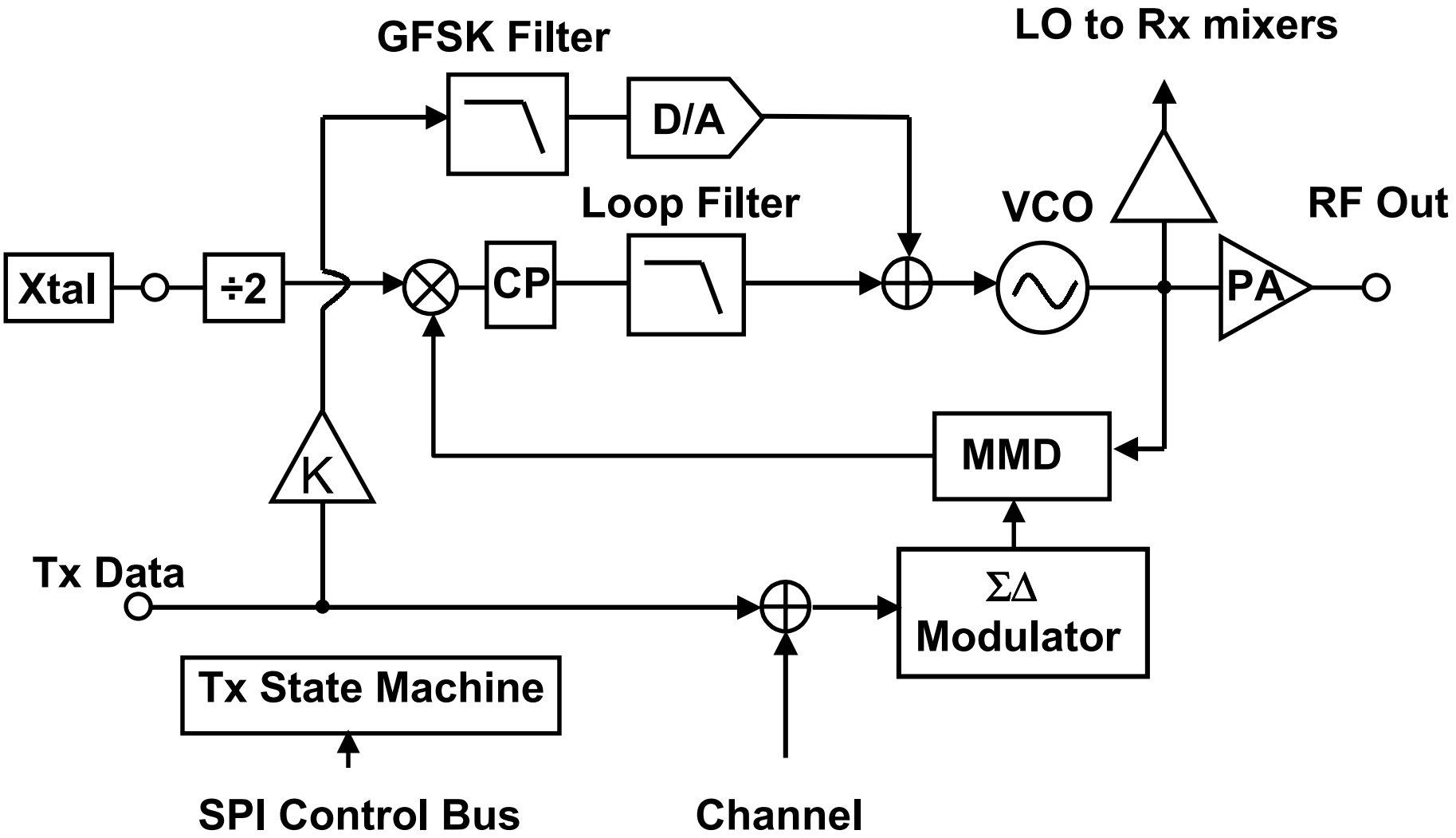
- Bluetooth for portable applications
  - Average power consumption 22mW @+2dBm
- Full integration
  - PLL, VCO, PA, IF filters, demodulator
- How was this achieved?
  - Careful architecture choice (direct modulation,low IF)
  - 1.6V - 3.0V operation
  - 0.5μm SiGe BiCMOS process

Transceiver Block Diagram



- 2-level GFSK Transmitter at 1Mb/s
  - $\Delta\Sigma$ controlled fractional-N synthesizer
  - Direct two-point modulation at RF
  - Modulation deviation calibration
- Receiver
  - Low IF 7–pole image reject complex IF filtering
  - Automatic IF filter tuning
  - Distributed feedforward AGC
  - Complex PLL based digital demodulator

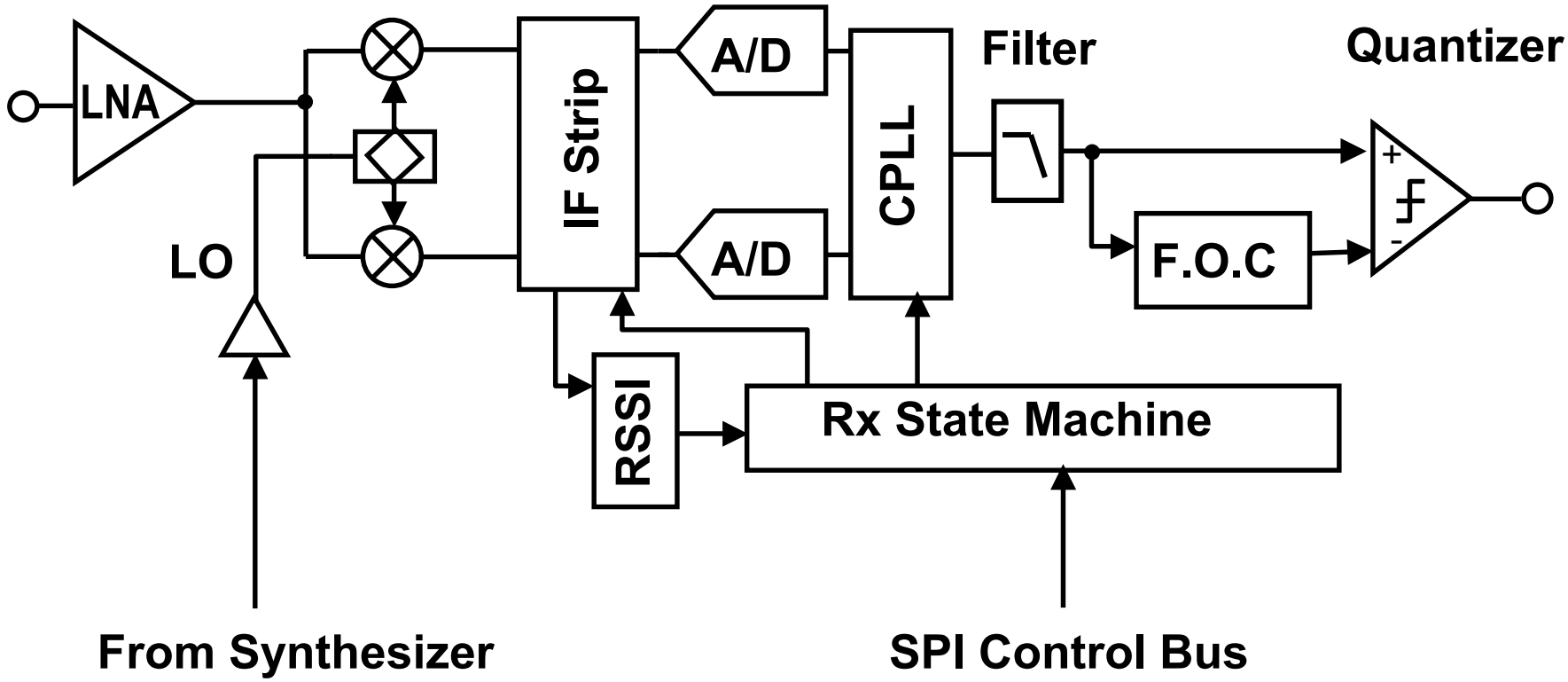
Transmitter Block Diagram



Transmitter Advantages

- Lower parts count than I/Q upconversion
  - No direct digital synthesizer required
  - No I/Q upconversion mixers required
  - No sideband rejection required
- Direct closed loop modulation
  - Carrier locked during transmission
- Fractional-N allows lower division ratios

Receiver Block Diagram

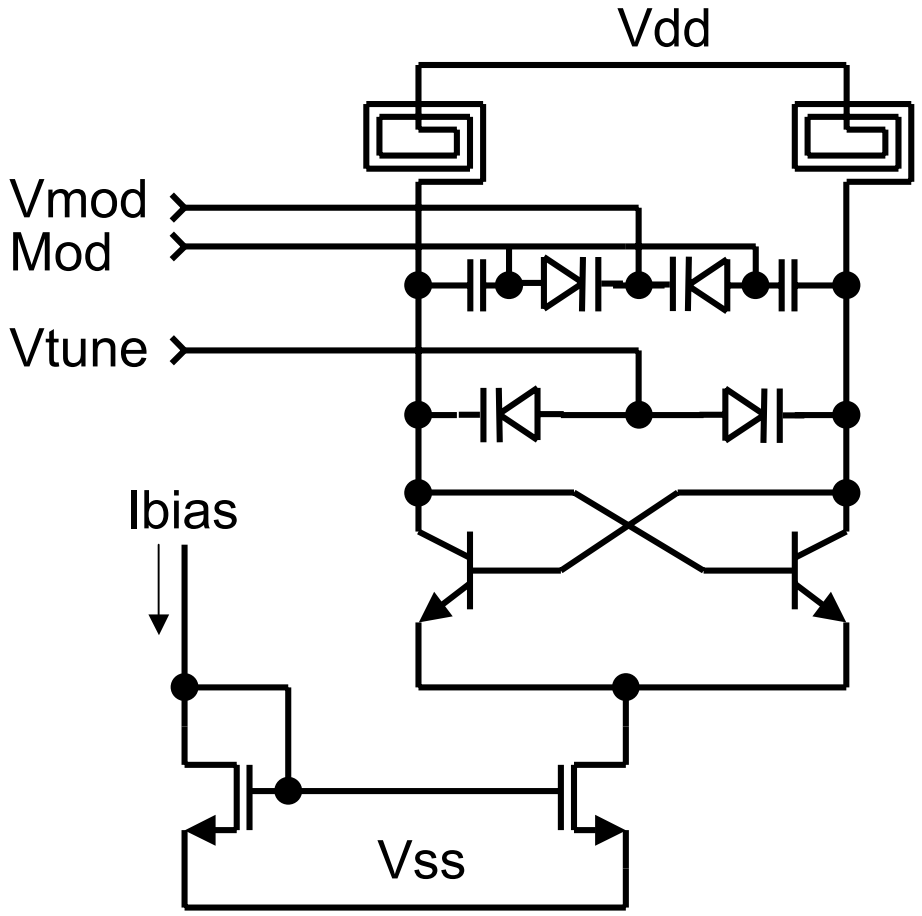


Receiver Advantages

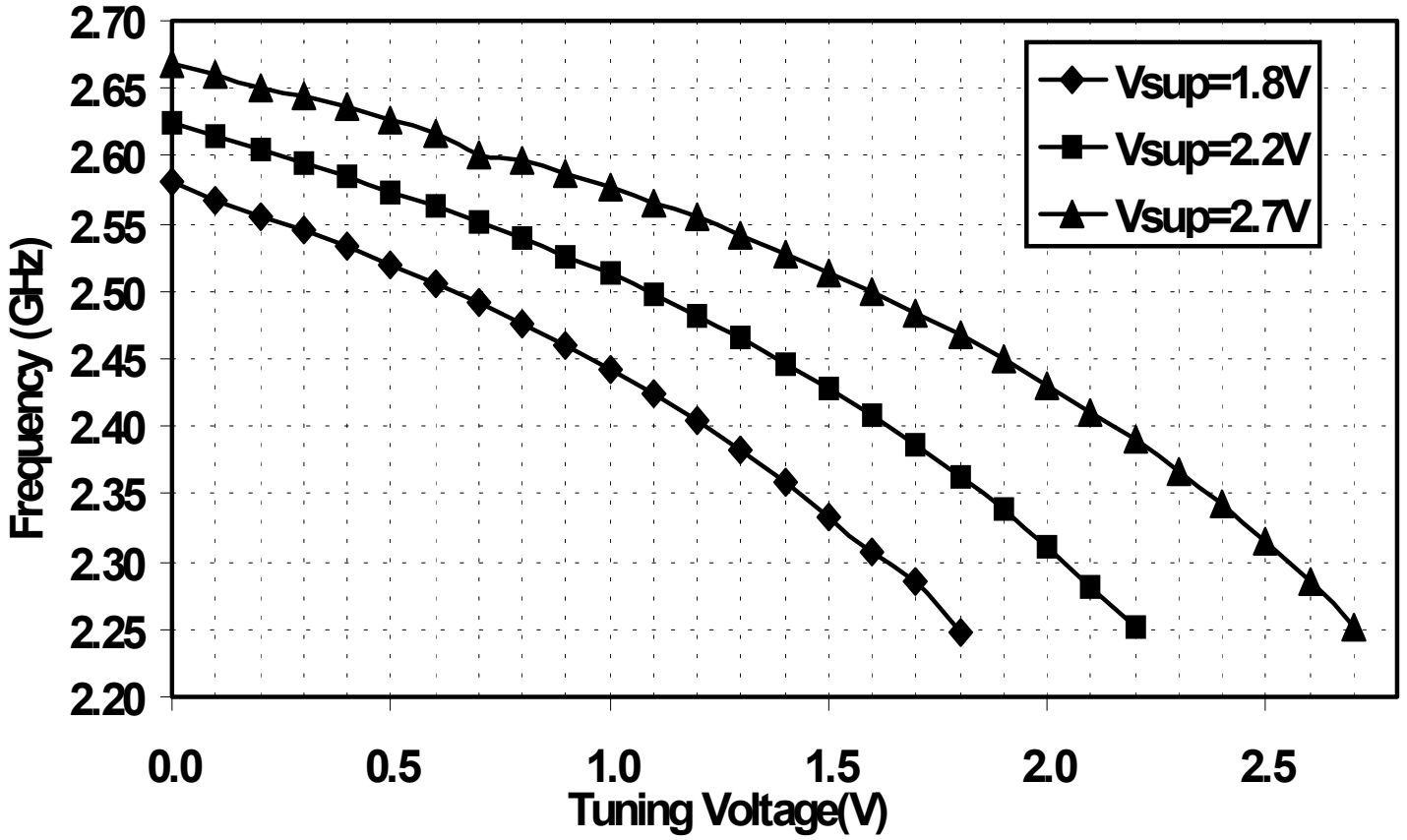
- Low IF uses complex filters for image rejection and pole count reduction
- Dynamic DC offsets are mitigated
- Distributed feedforward AGC is stable
- Complex domain provides four phases for fast AGC response
- No drivers required for off chip filters
- Complex PLL demodulator requires no external components

2.5GHz VCO with Modulation Port

- **On chip spiral inductors Q=7**
- **1MHz/V modulation port**
- **Phase noise –110dBc/Hz @ 1MHz**
- **Power 1mA @ 1.6V**



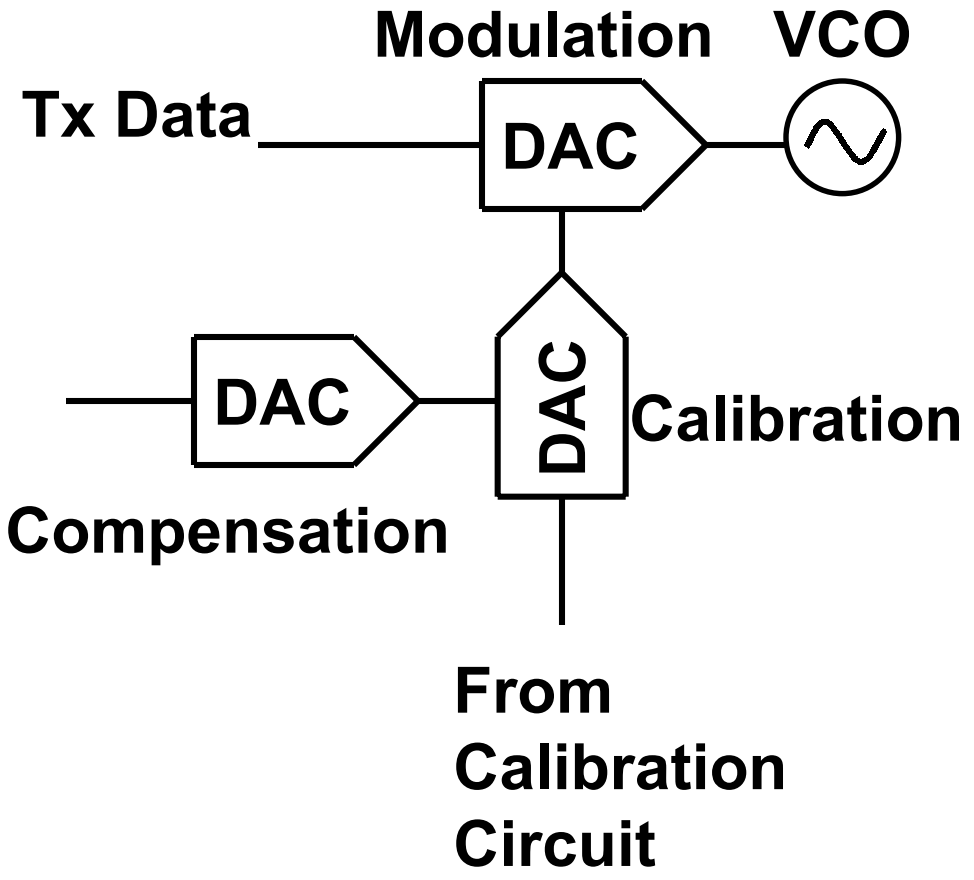
Measured VCO Tuning Curve



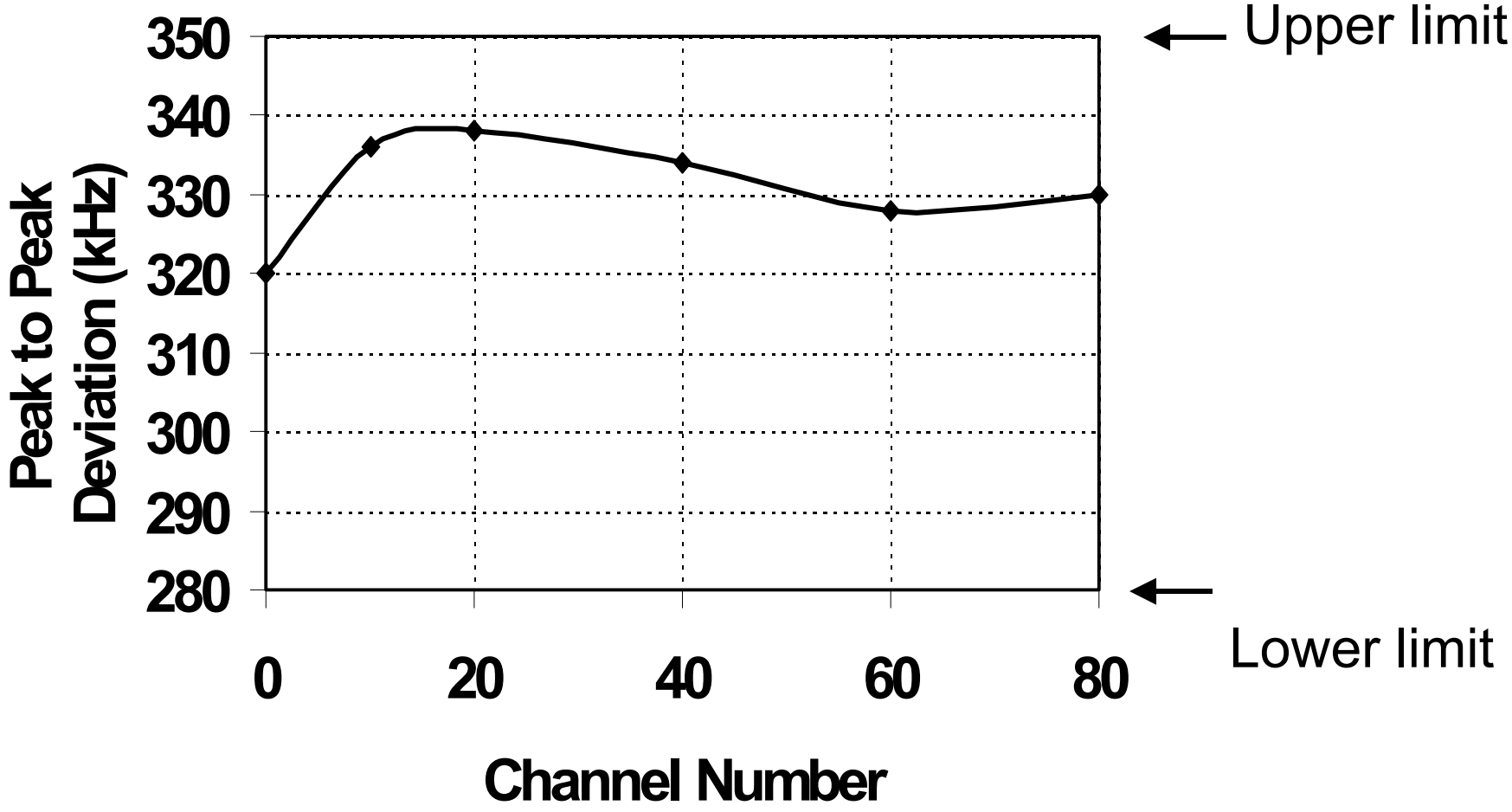
Δf = 330MHz @ 1.8V

Modulation Deviation Setting

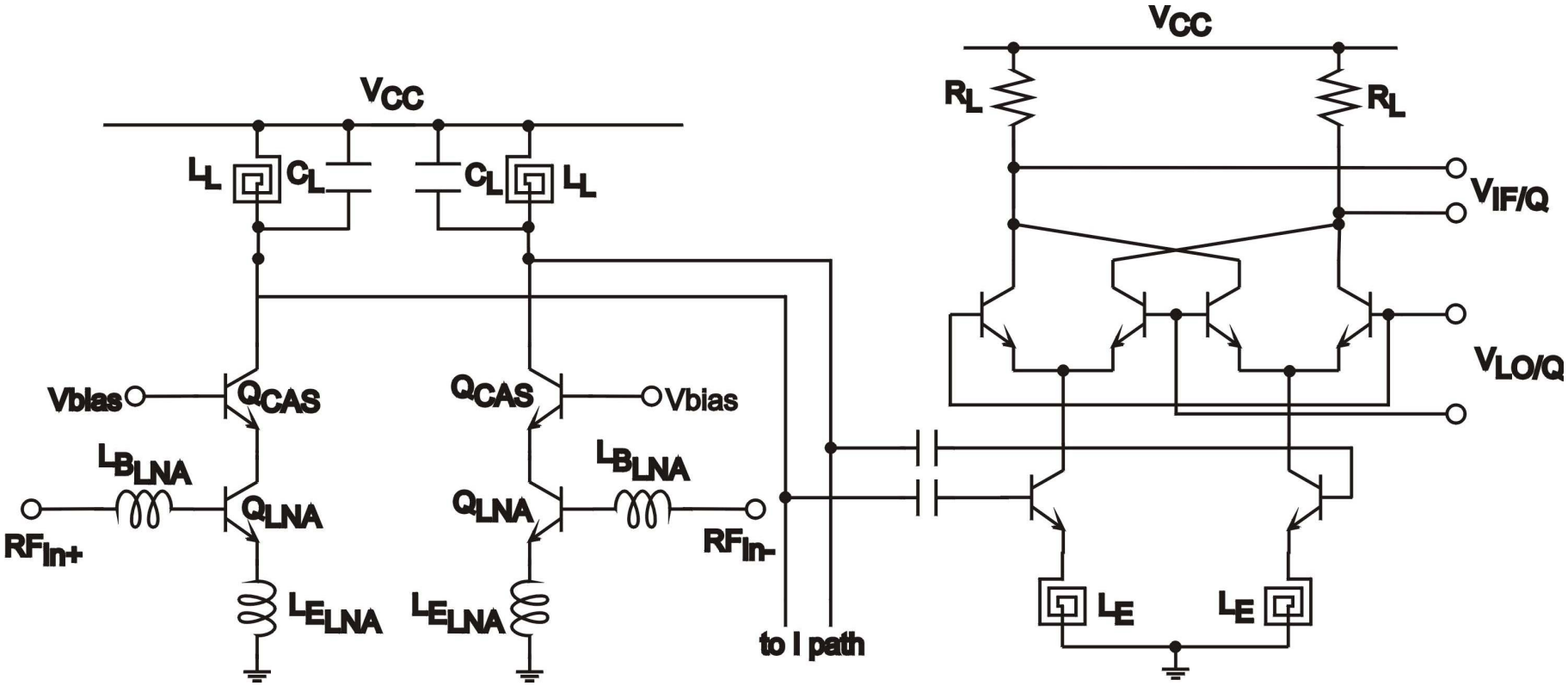
- Calibration circuit sets fullscale range of modulation DAC
- Compensation DAC is for fine tuning of the deviation
- 6% Deviation variation across band



Modulation Deviation Variation Over Transmit Band

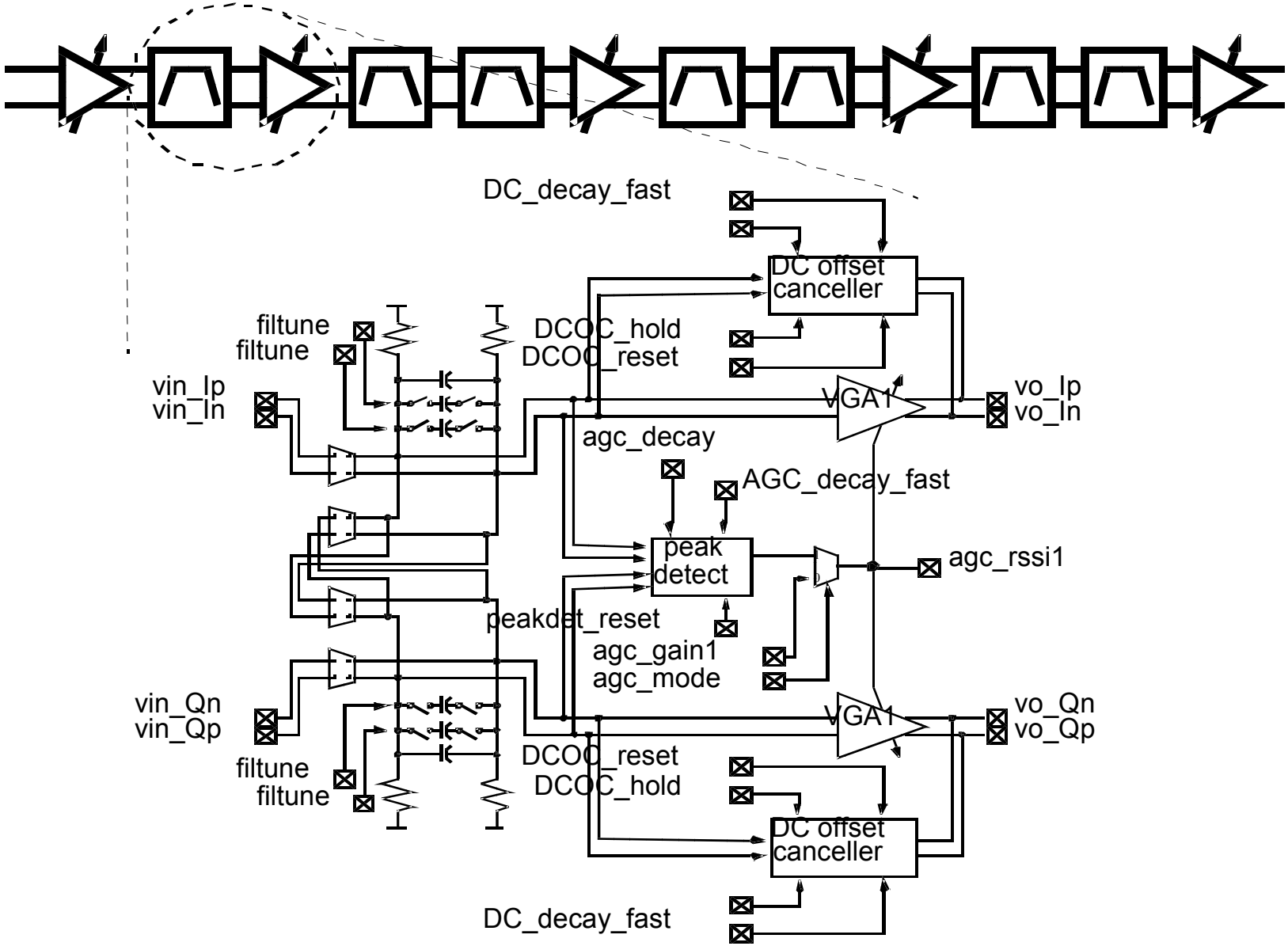


RF Front-end



- Small signal gain = 14dB
- Noise figure = 6.5dB
- IP3 = -15dBm
- Image rejection > 21dB
- Power = 4.5mA @ 1.8V
- 1V operation possible

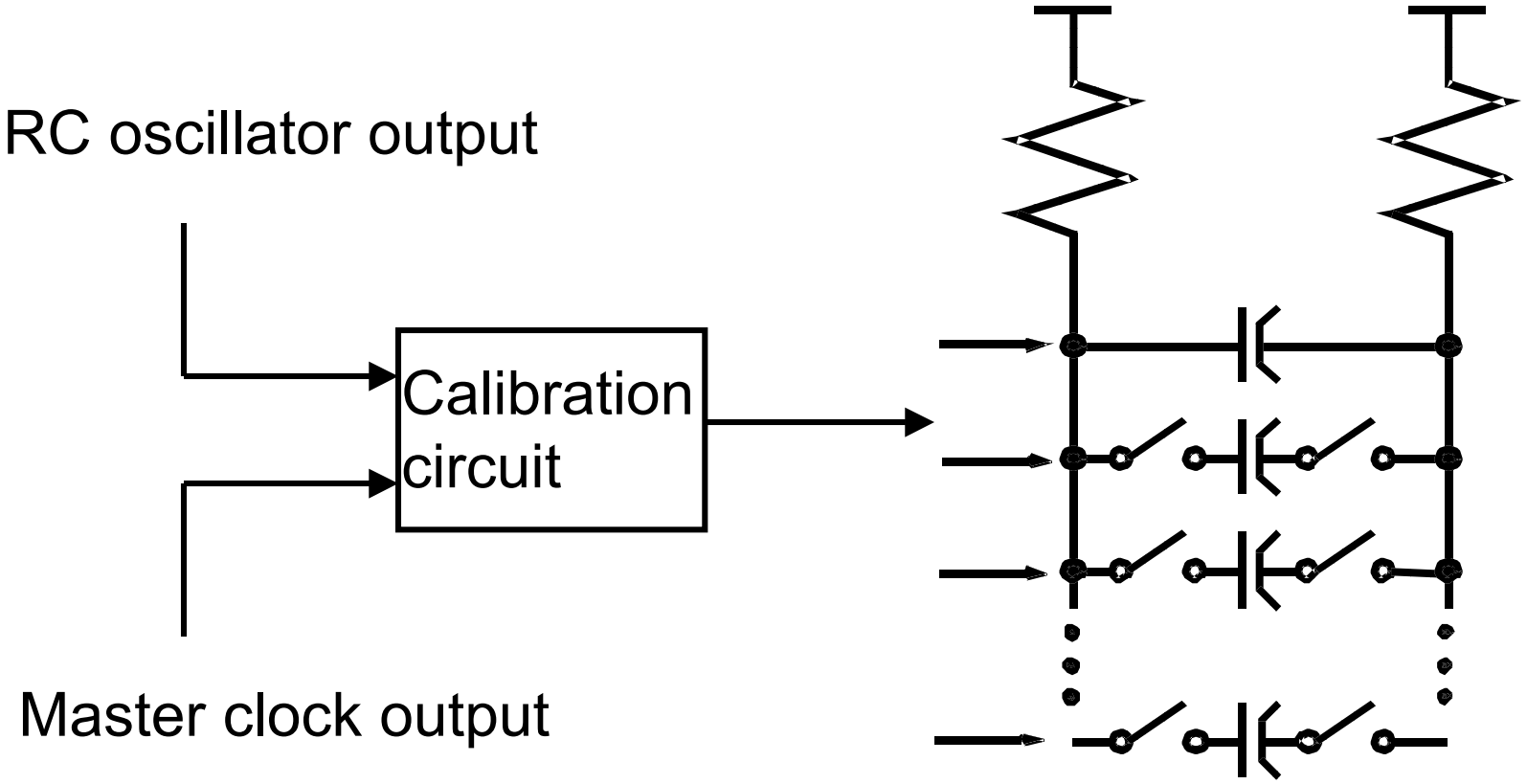
IF Filters


DC_decay_fast
DC offset canceller
filtune
filtune
DCOC_hold
DCOC_reset
vin_Ip
vin_In
VGA1
vo_Ip
vo_In
agc_decay
AGC_decay_fast
peak detect
agc_rssi1
peakdet_reset
agc_gain1
agc_mode
vin_Qn
vin_Qp
VGA1
vo_Qn
vo_Qp
DCOC_reset
DCOC_hold
filtune
filtune
DC offset canceller
DC_decay_fast

IF Filter

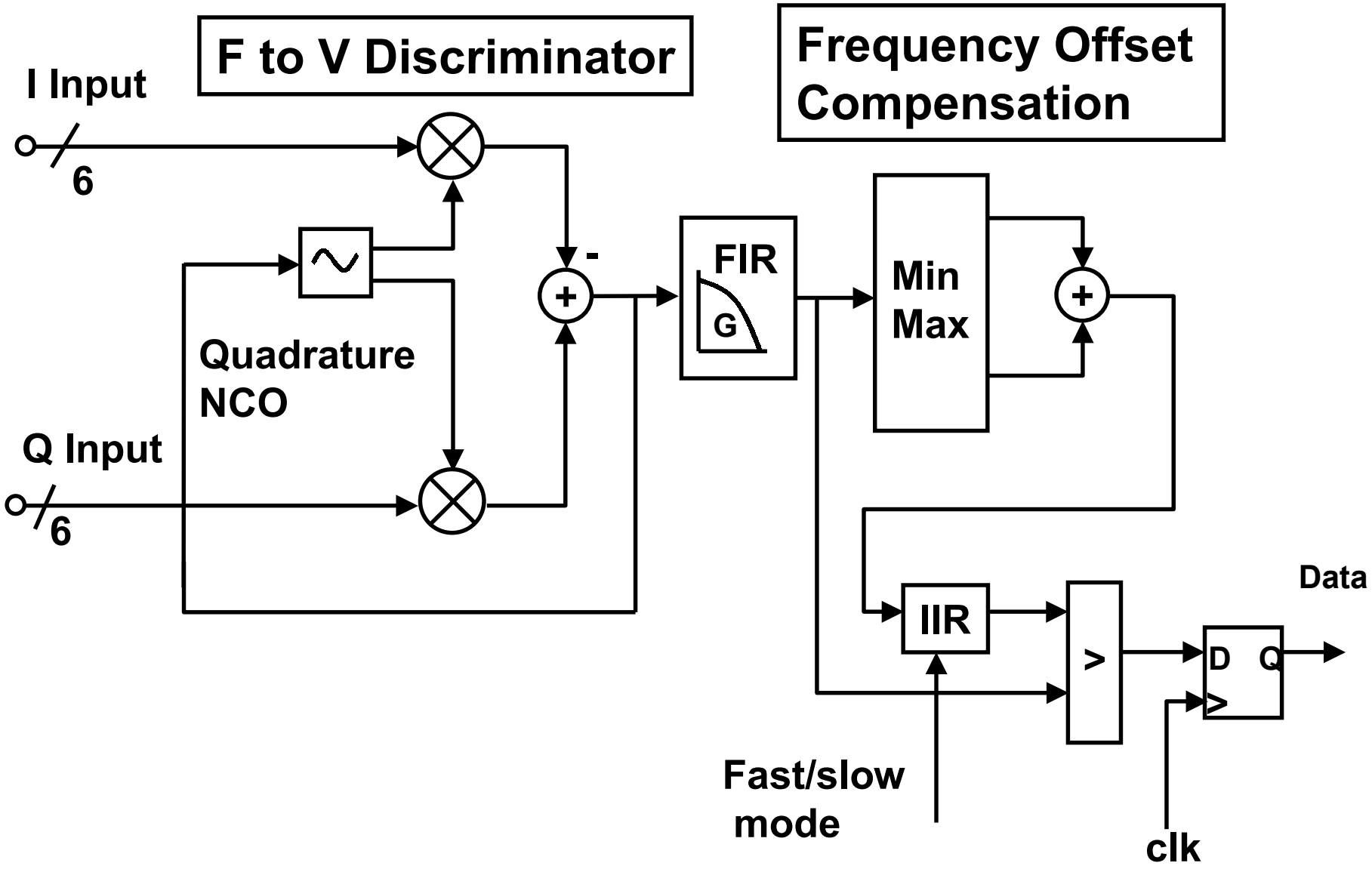
- No external components
- 7 complex poles and 5 VGA's
- Automatic tuning ±200kHz
- VGA gain: 84dB dynamic range with 1dB resolution
- AGC range 60dB

RC Oscillator Based IF Filter Tuning



±200kHz center frequency tuning range

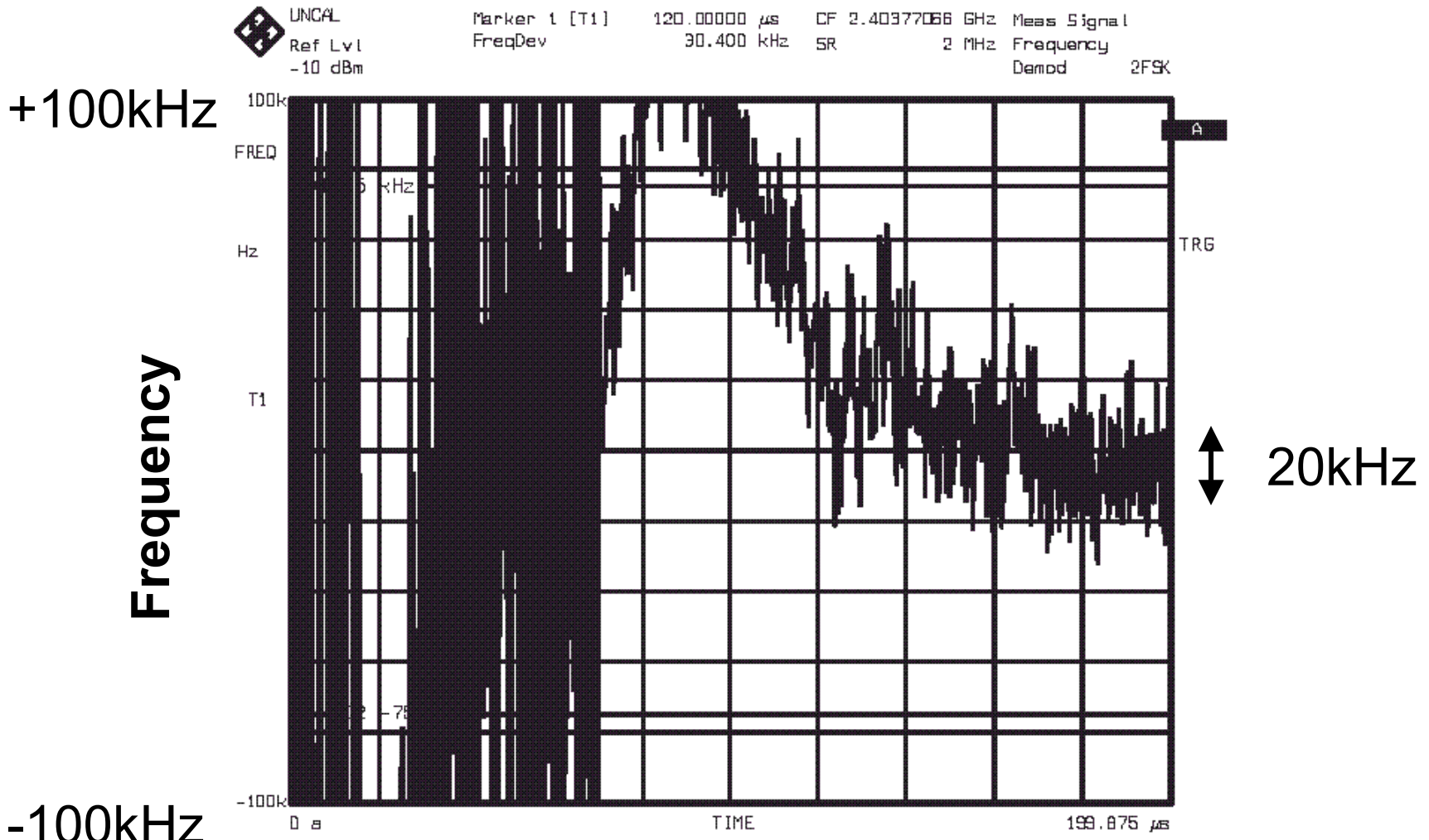
Complex PLL Demodulator



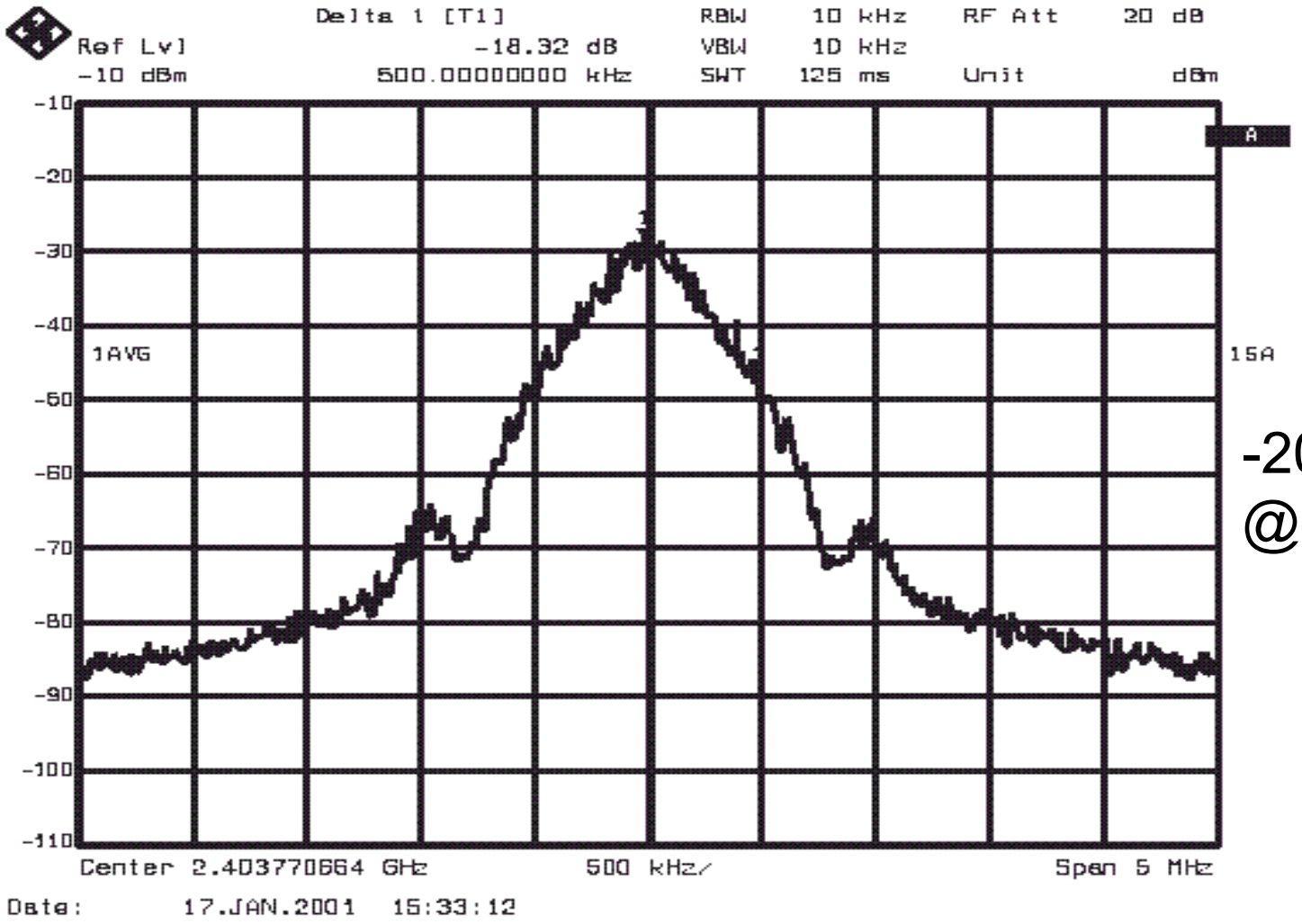
Complex PLL Advantages

- Coherent FM demodulator
- Can tolerate ±325kHz offset
- 1st order control system
  - Unconditionally stable
  - Acquisition range = loop gain
- Acquisition time < 1μs
- Supports 4-level GFSK demodulation

Settling Curve for 80MHz Hop



Transmit Spectral Mask

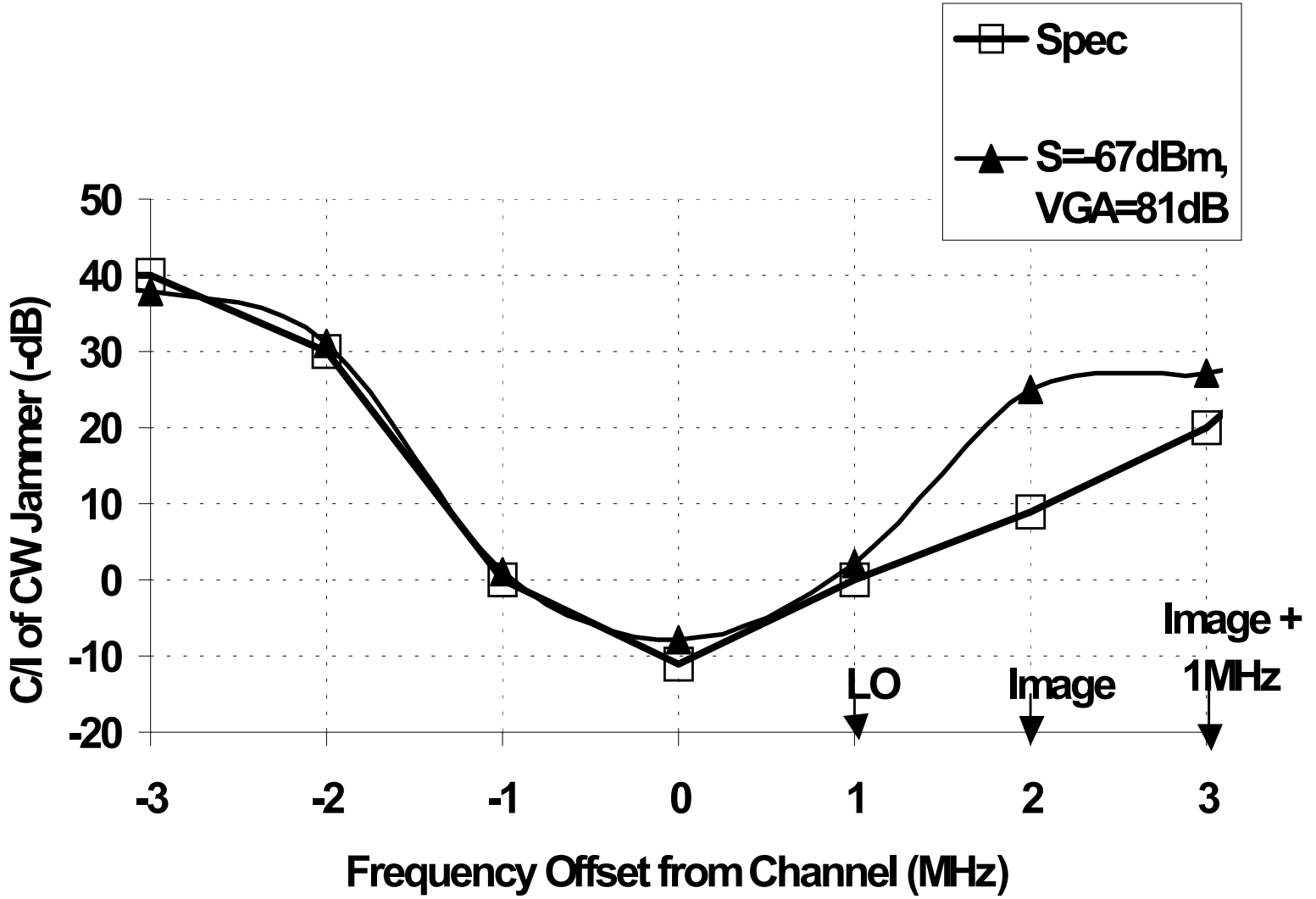


Power (dBm)

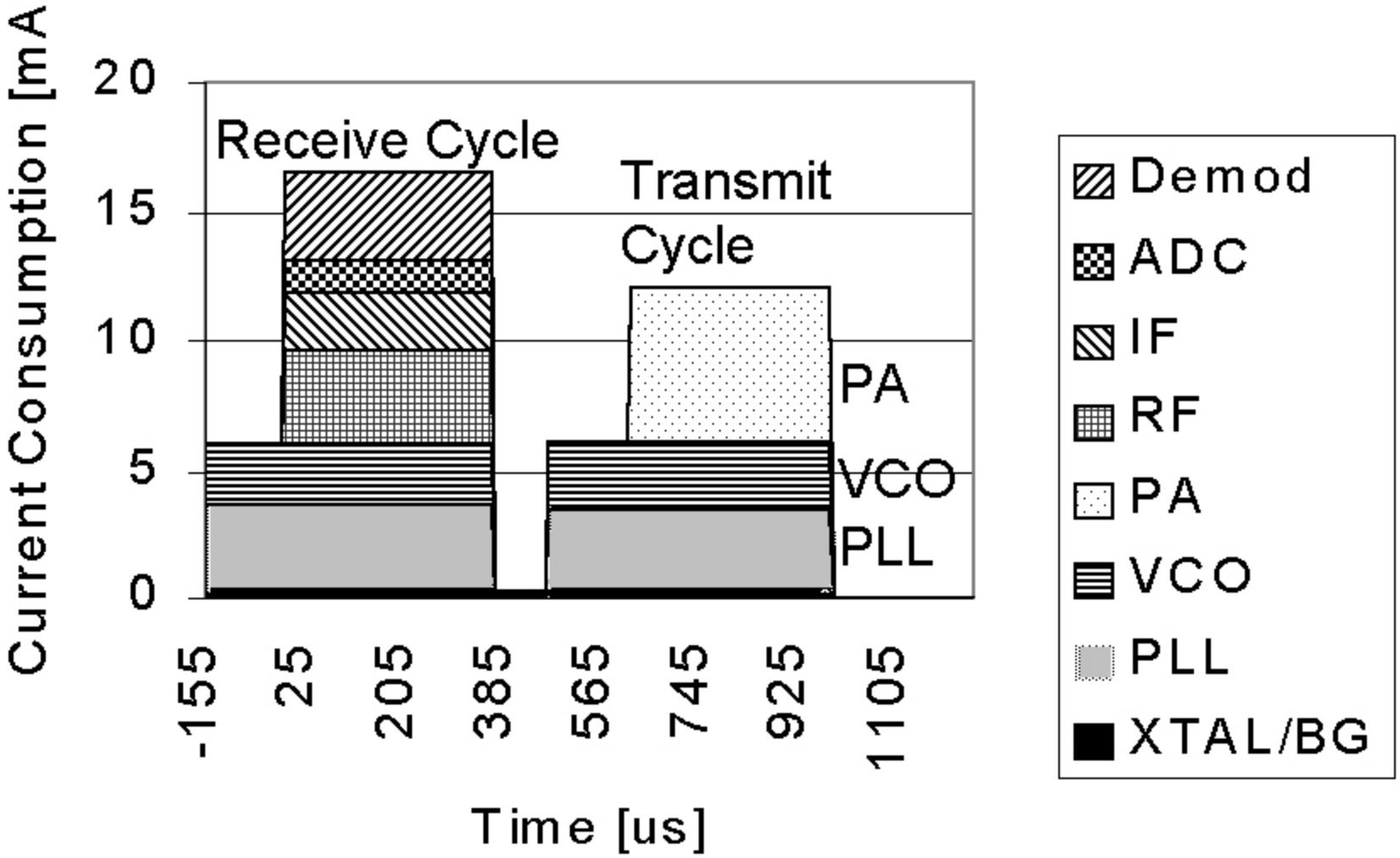
-20dBc
@±500kHz

Frequency (500kHz/div)

Blocker Rejection



Current Consumption by Block



Power Comparison

	Standard	**Tx Power**	**Peak Power Consumption**	**Technology**
J. Craninckx et al.	DECT	-6dBm	60mA@2.7V =162mW	BiCMOS
G. L. Puma et al.	DECT		50mA@3.1V =155mW	Si Bipolar
F. Op ‘T Eynde et al.	Bluetooth (BB)	+2dBm	50mA@2.5V =125mW	0.25um CMOS
H. Darabi et al.	Bluetooth	+5dBm	47mA@2.7V =127mW	CMOS
This Work	**Bluetooth**	**+2dBm**	**17mA@1.8V =31mW**	**SiGe BiCMOS**

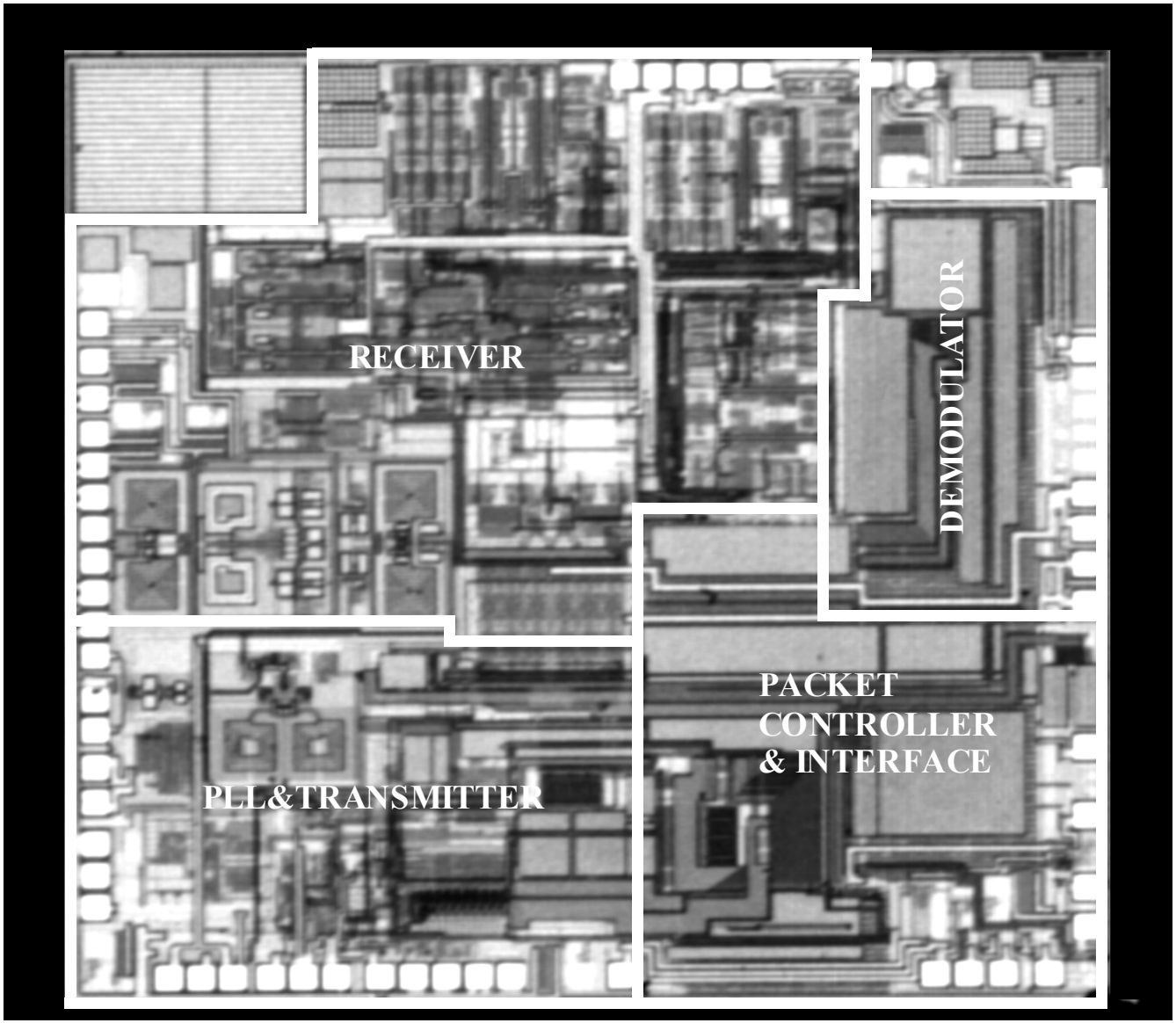
Key Performance Summary

Parameter	Bluetooth Specification	Achieved
Centre frequency	±75kHz (220us)	±75kHz (120us)
Transmit mask	-20dBc @ ±550kHz	-20dBc @ ±500kHz
Sensitivity (BER=10^{-3})	-70dBm	-78dBm
Co-Channel interference (C/I)	11dB	9dB
1MHz Blocker (C/I)	0dB	0dB
2MHz Blocker (C/I)	-30dB	-30dB
3MHz Blocker(C/I)	-40dB	-39dB

Conclusions

- Fully integrated Bluetooth transceiver
- Direct two-point modulation
- Complex IF filtering with on chip tuning
- 1.6V - 3.0V operation
- Average power consumption 22mW @ +2dBm Tx power

Photo Micrograph

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