ECEN620: Network Theory
Broadband Circuit Design
Fall 2014

Lecture 13: Frequency Synthesizer Examples

Sam Palermo

Analog & Mixed-Signal Center

Texas A&M University

Agenda

- Frequency Synthesizer Examples
  - Design of Frequency Synthesizers for Short Range Wireless Transceivers
  - A Multi-Standard Frequency Synthesizer

Design of Frequency Synthesizers for Short Range Wireless Transceivers

Ari Y. Valero - López

Department of Electrical Engineering
Analog & Mixed-Signal Center
Texas A&M University

February 23th, 2004

Most Popular Wireless Standards

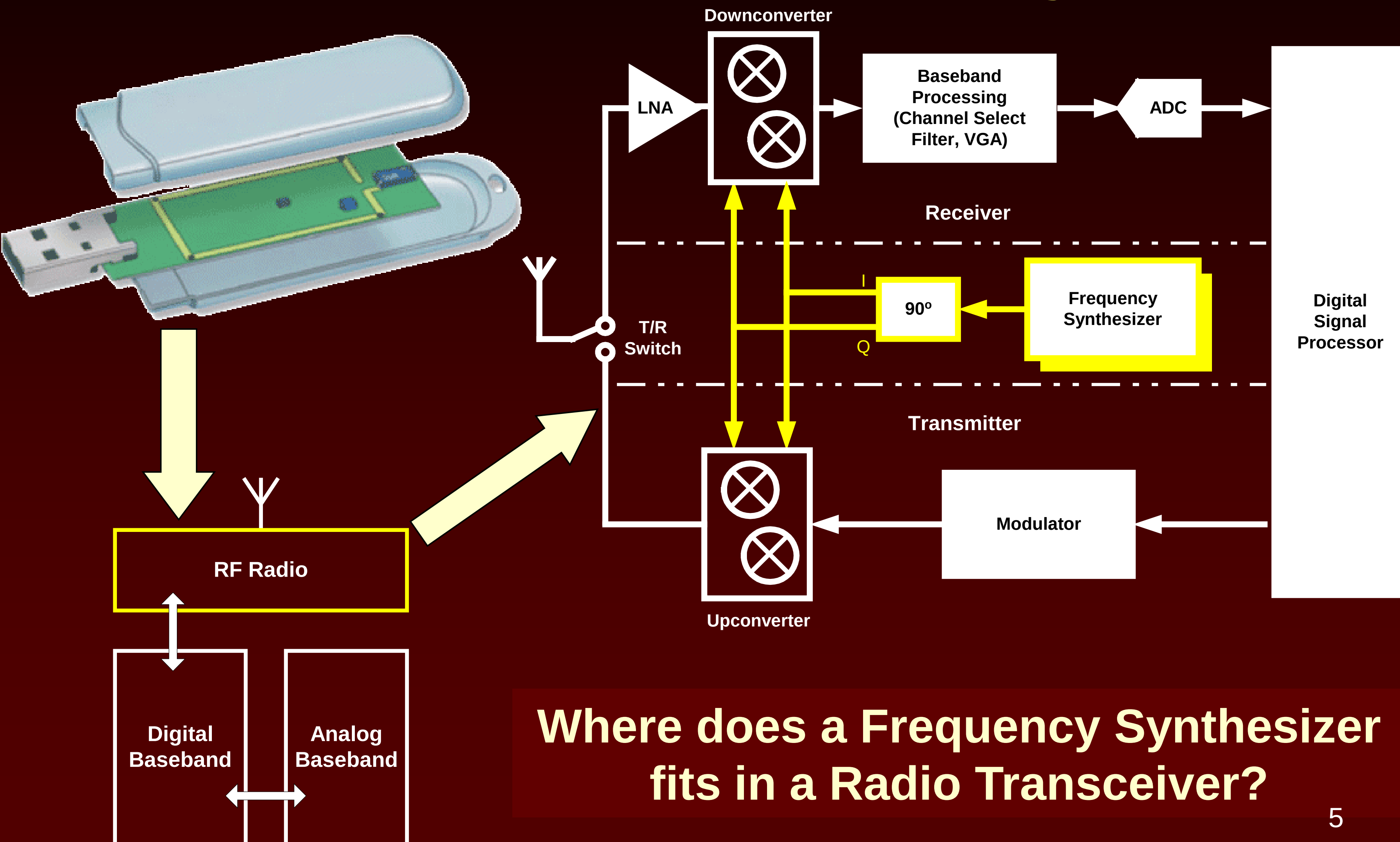
WirelessLAN 802.11
11a (5.25GHz, 54Mbps, 50m)
11b (2.45GHz, 11Mbps, 100m)
11g (2.45GHz, 24Mbps, 100m)

Short Range Wireless

UWB
(3.1-10.9GHz, 110Mbps, 10m)

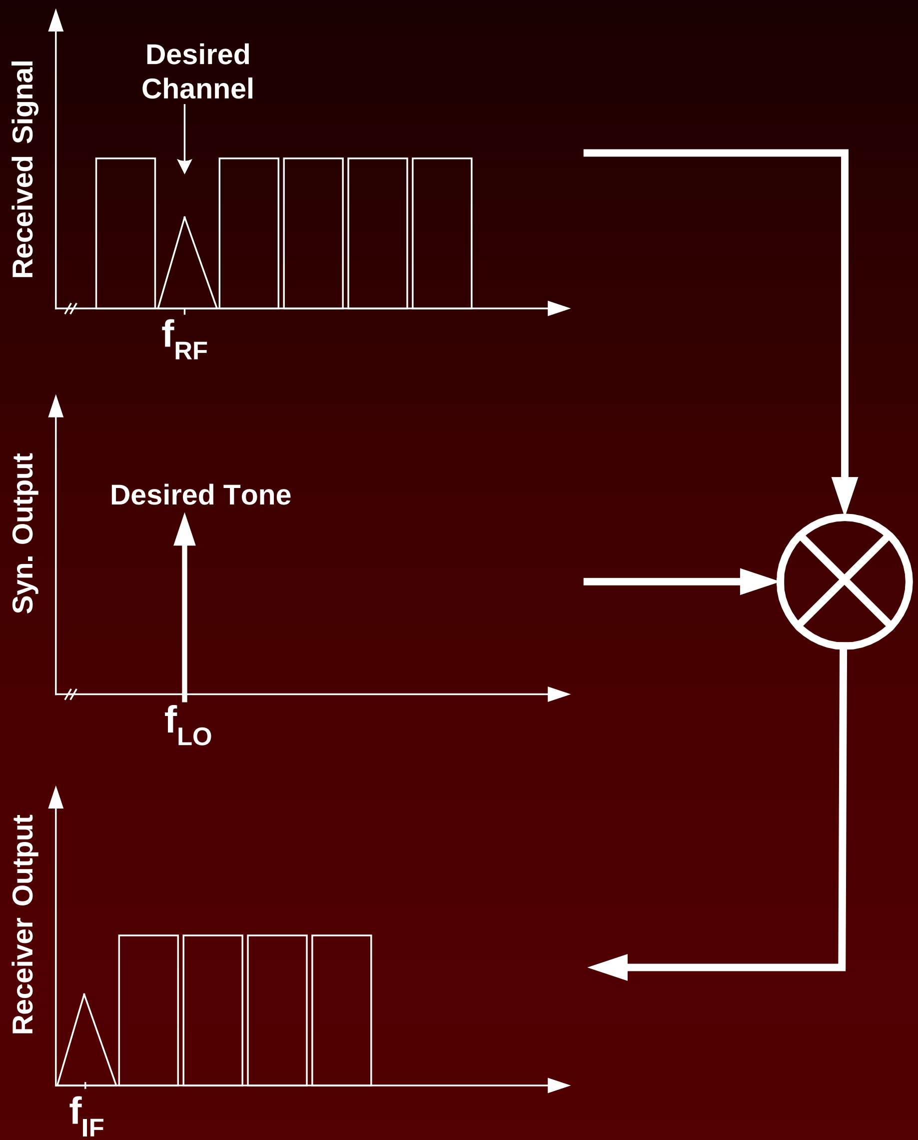
Bluetooth
(2.45GHz, 1Mbps,10m)

Frequency Synthesizer in a Wireless Communication System



Where does a Frequency Synthesizer fits in a Radio Transceiver?

Function of a Frequency Synthesizer in a Radio

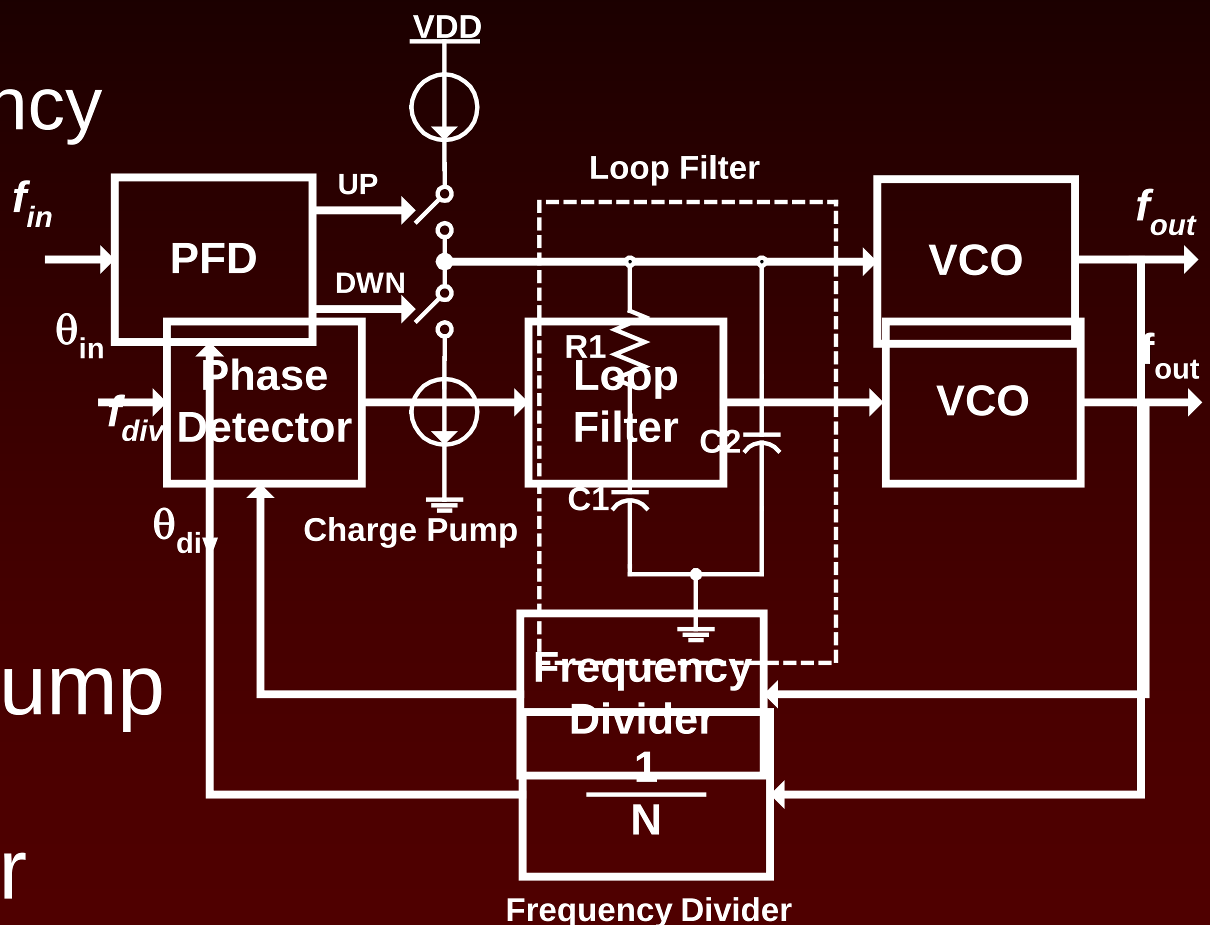


The Frequency Synthesizer generates the required frequency reference for selection of a communication channel

The desired channel is downconverted to a frequency corresponding to: $f_{IF} = f_{RF} - f_{LO}$

Frequency Synthesizer Building Blocks

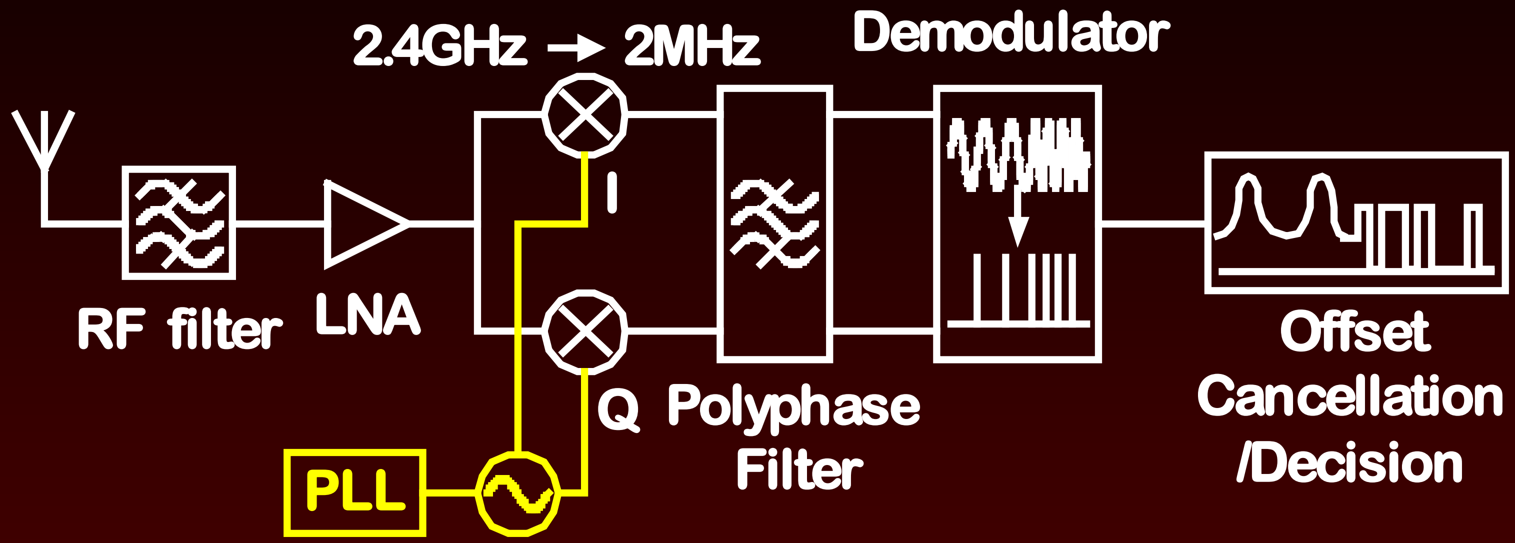
- VCO and Frequency Divider operate at high frequency



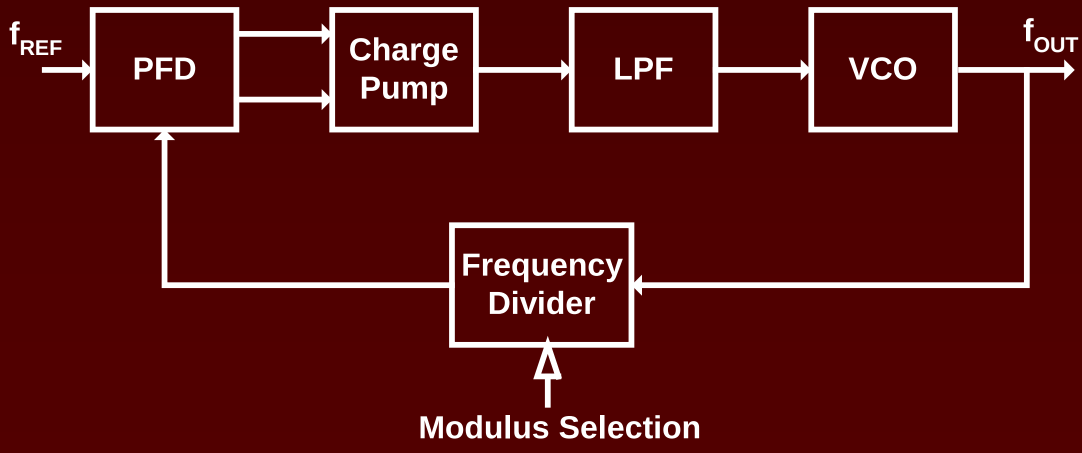
- PFD, Charge Pump and LPF generate proper control voltage of VCO

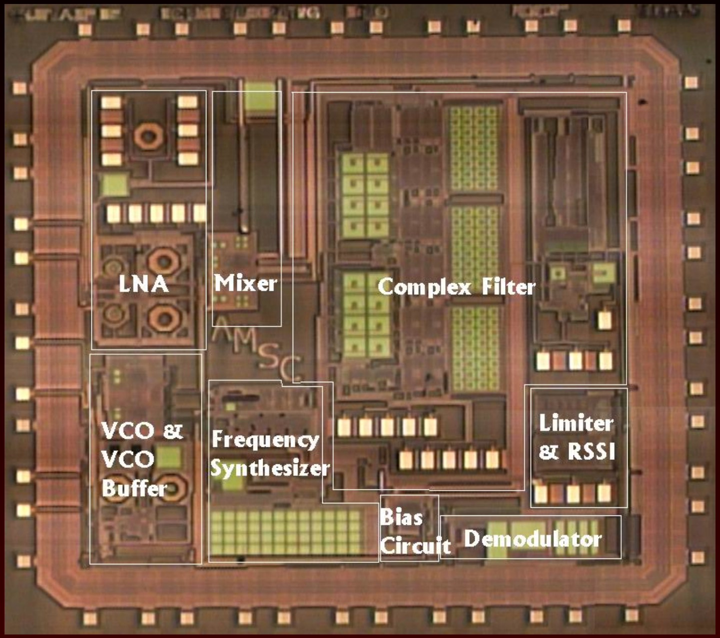
$$\theta_{in} = \theta_{div} \Rightarrow f_{in} = f_{div} = f_{out}/N$$

FS for Bluetooth Receiver

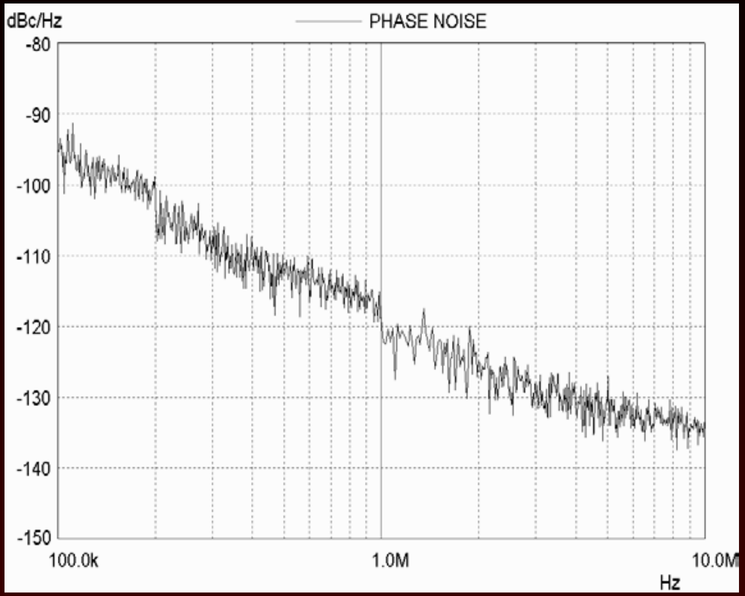


Bluetooth Low IF Receiver in 0.35μm CMOS





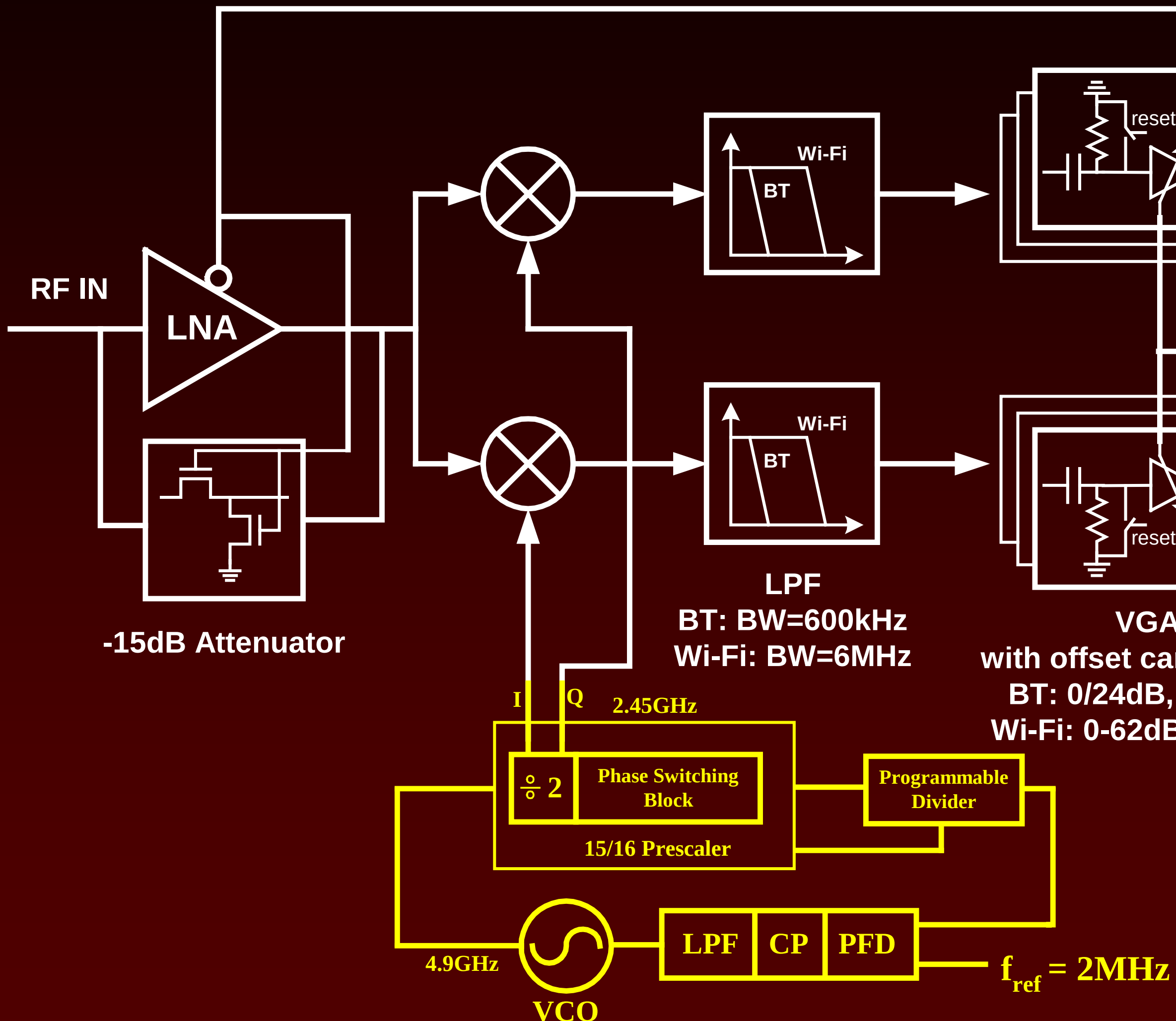
Micrograph



Phase Noise Measurement

- Results
  - Tuning Range: 2.388 - 2.550 GHz
  - PN: -120dBc / Hz @ 1MHz
  - Frequency Step 1MHz
  - Power: 12 mA

Dual Mode Receiver



Direct Conversion Bluetooth/Wi-Fi Receiver

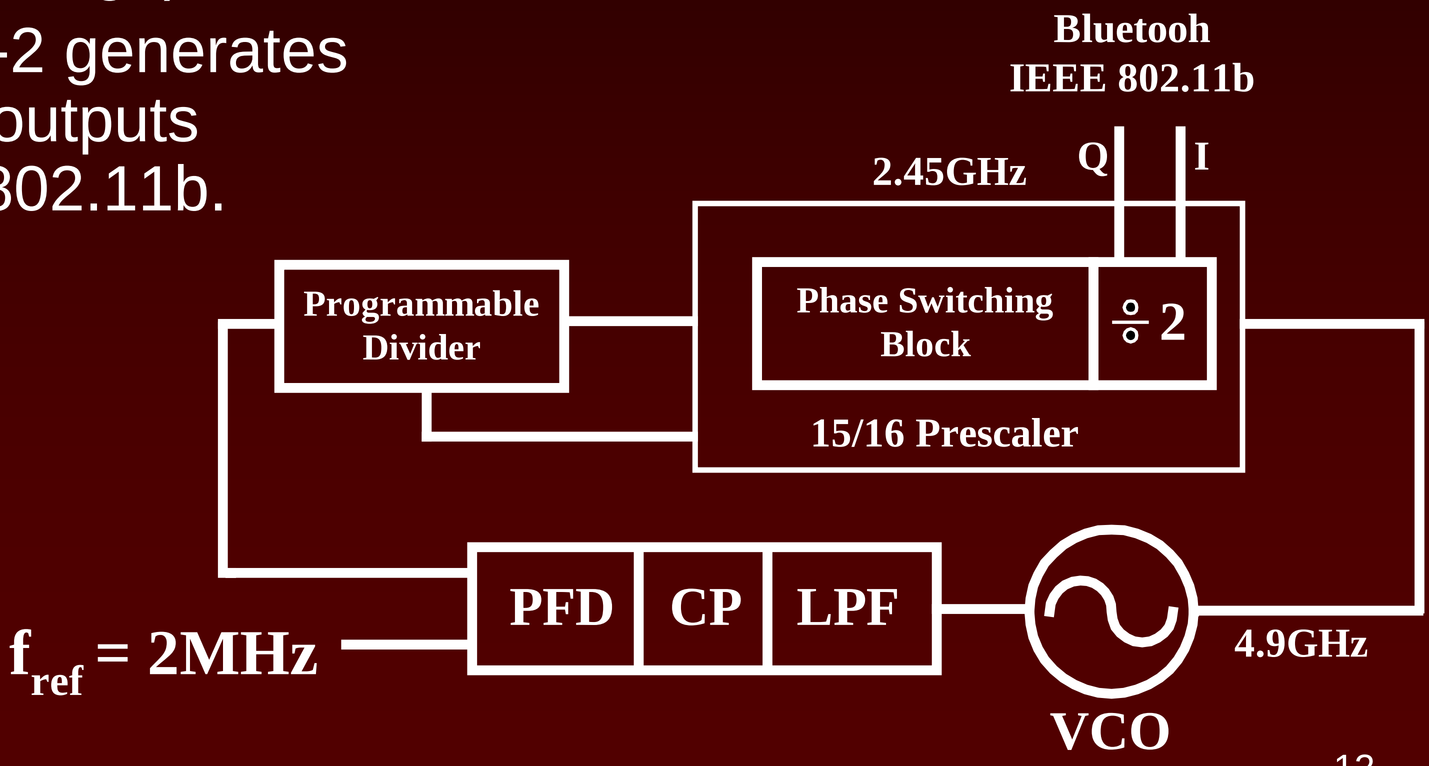
Frequency Synthesizer Specifications

	Bluetooth	IEEE 802.11b
Frequency Range	2401 – 2480 GHz	2401 – 2480 GHz
Channel Spacing	1 MHz	5 MHz
Settling time (max)	220 μs	224 μs
Phase Noise	-124 dBc/Hz @ 3 MHz	-125 dBc/Hz @ 25 MHz
Center frequency accuracy	±75 kHz	±60 kHz

- Bluetooth specifications are more stringent
- Complying with Bluetooth specs covers WiFi

Frequency Synthesizer Architecture

- An Integer N Frequency Synthesizer architecture is used.
- The VCO oscillates at 5 GHz to accommodate all the standards (requires 10% tuning range).
- A Divide-by-2 generates quadrature outputs for BT and 802.11b.

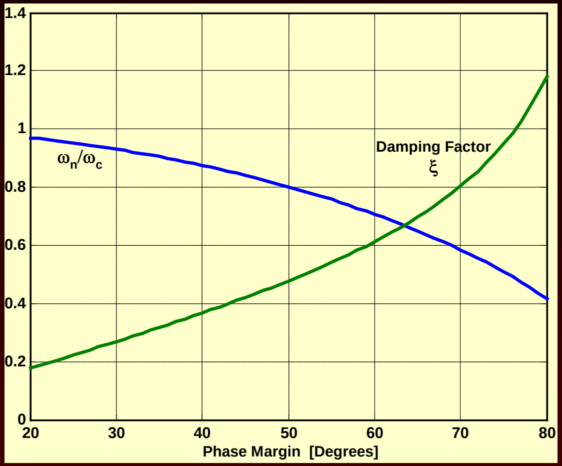


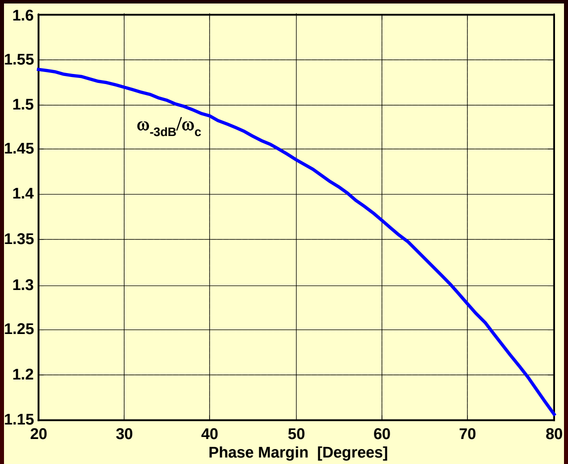
Design Considerations

- **Phase Margin**

$$\phi_m = \tan^{-1}\left(\sqrt{\frac{\omega_{p2}}{\omega_z}}\right) - \tan^{-1}\left(\sqrt{\frac{\omega_z}{\omega_{p2}}}\right)$$

$$\phi_m = \tan^{-1}\left(\sqrt{\frac{C_1}{C_2}+1}\right) - \tan^{-1}\left(\frac{1}{\sqrt{\frac{C_1}{C_2}+1}}\right)$$





$$\zeta = \frac{\tau}{2}\sqrt{\frac{K_{pd}K_f K_{vco}}{N}} = \frac{\sin(\phi_m)}{2\sqrt{\cos(\phi_m)}}$$

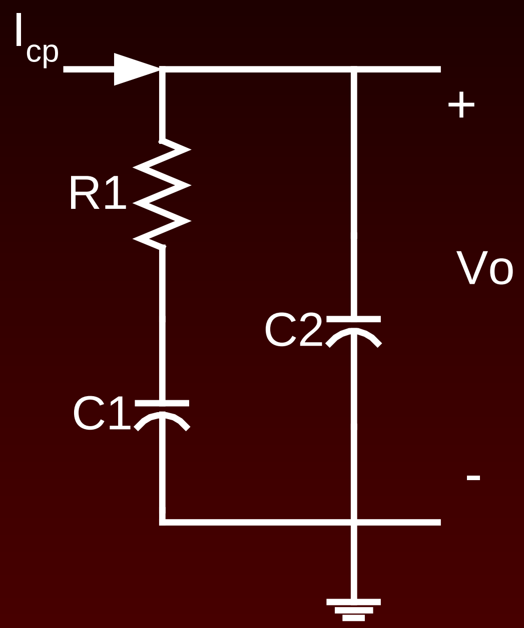
$$\omega_{-3dB} = \omega_n\sqrt{\left(2\zeta^2+1\right)+\sqrt{\left(2\zeta^2+1\right)^2+1}}$$

- **Settling Time**

$$t_{lock} = \begin{cases} \dfrac{\ln\left(\dfrac{\Delta N f_{ref}}{\varepsilon\sqrt{1-\zeta^2}}\right)}{\omega_n \zeta} & \zeta < 1 \\[2ex] \dfrac{1}{\left(\xi-\sqrt{\xi^2-1}\right)\omega_n}\ln\dfrac{\left(\Delta N f_{ref}\sqrt{\xi^2-1}+\xi\right)}{\varepsilon 2\sqrt{1-\xi^2}} & \zeta > 1 \end{cases}$$

- Design Parameters
  - Loop Bandwidth
  - VCO Gain
  - Charge Pump Current
  - Loop Filter Components

Loop Filter



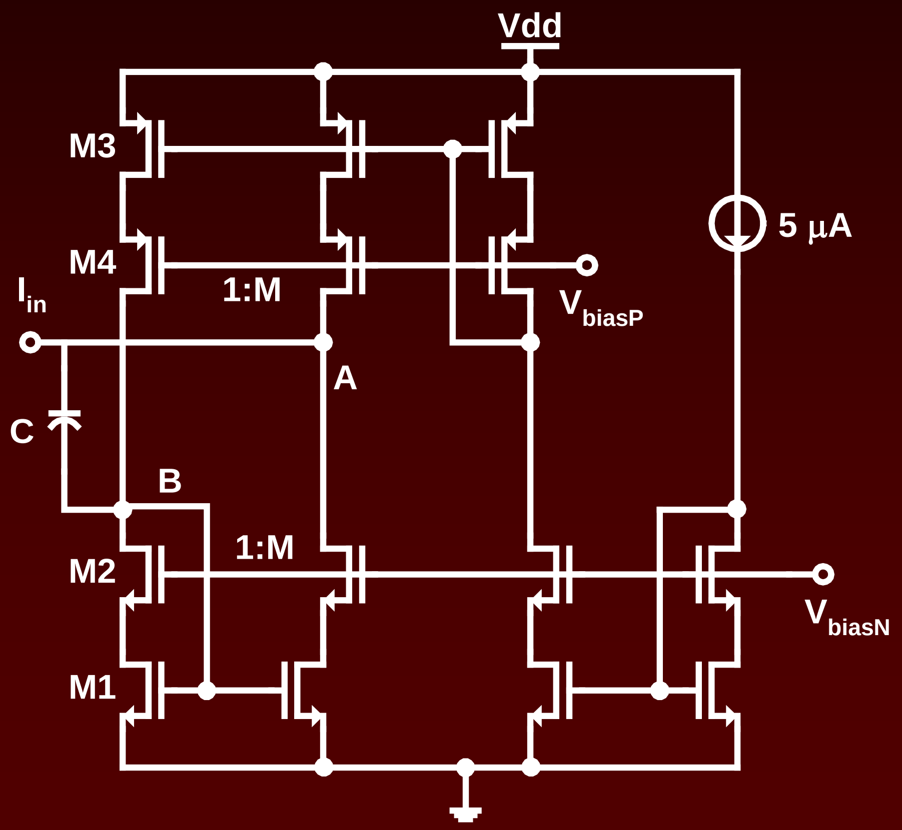
K_{vco} = 300MHz/V	C_1 = 340 pF
I_{cp} = 35 μA	C_2 = 26.15 pF
N = 2450	R_1 = 52.6 kΩ

- Trade offs
  - Settling Time
  - Close-in Phase Noise
  - Total Capacitance
  - Charge Pump Current

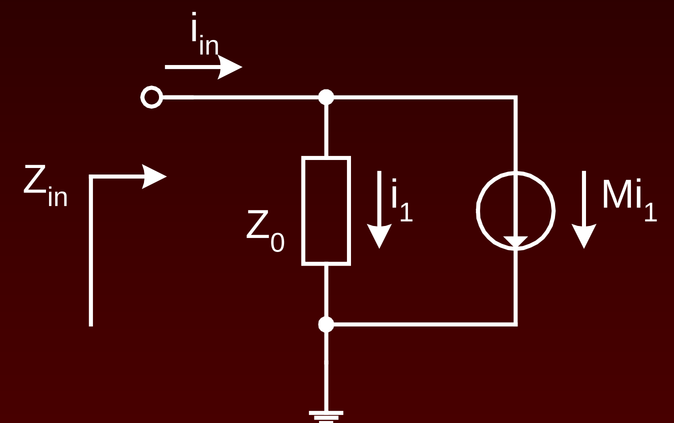
Loop Bandwidth = 35 kHz Phase Margin = 60°

Capacitance Multiplier

- Schematic

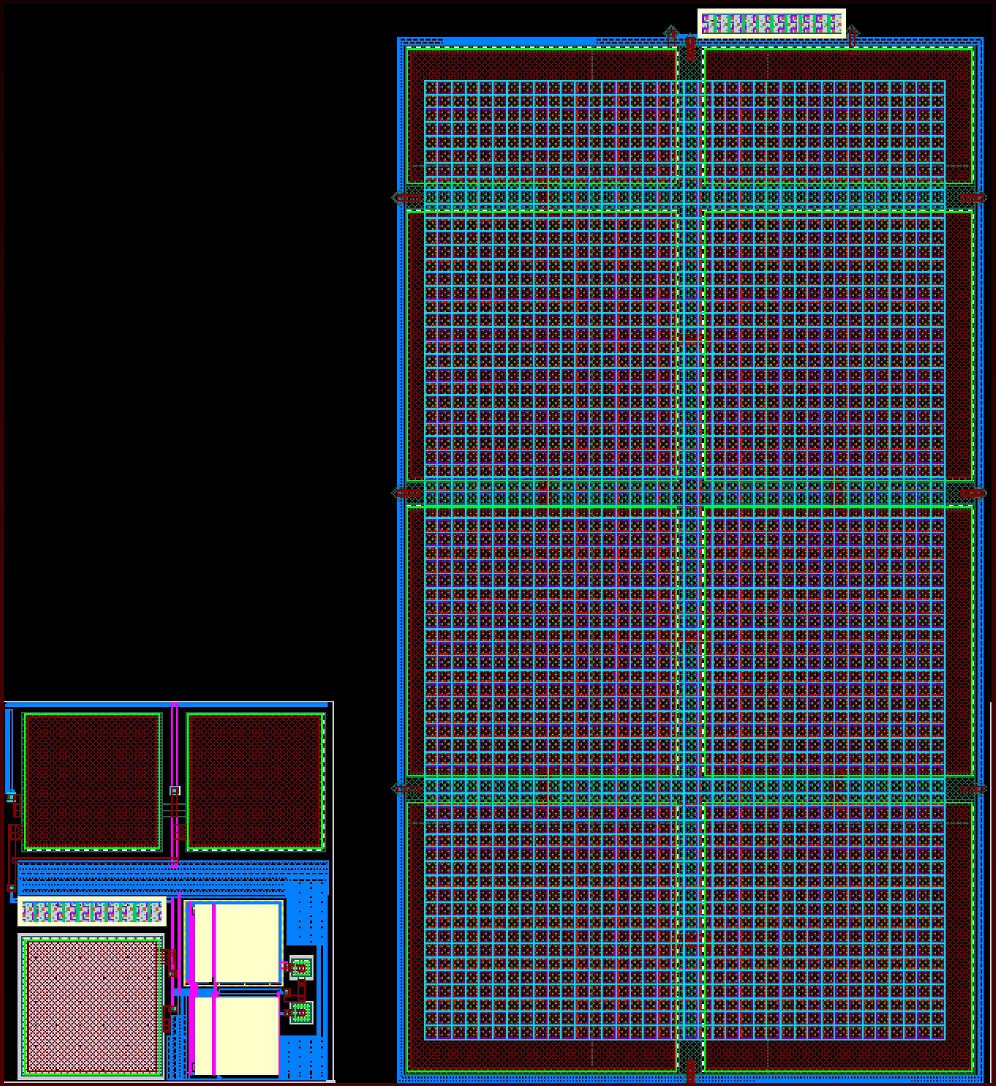


- Model



$$Z_{in} = \frac{Z_0}{M+1}$$

Loop Filter Layout

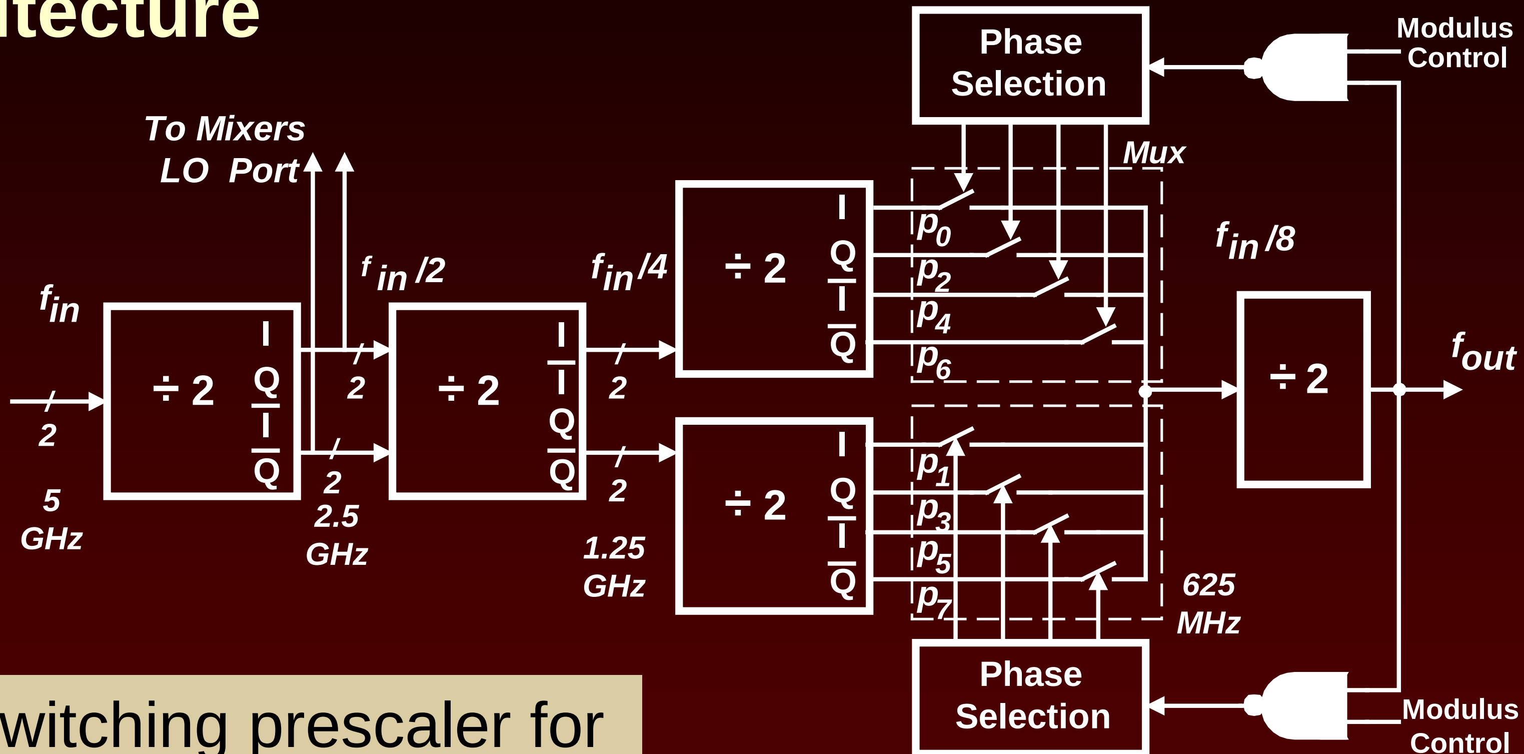


Active vs. Passive

- Active Filter.
  - Reduced area
  - 240μm x 280μm
- Passive Filter.
  - Reduced spurs
  - 430μm x 780μm

Phase Switching Prescaler

- **Architecture**



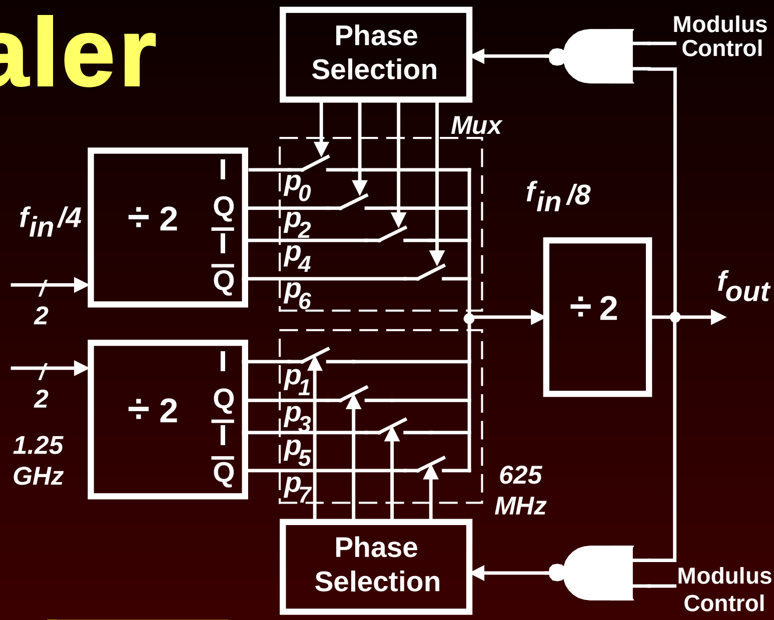
Phase switching prescaler for reduced power consumption compared with traditional architectures.

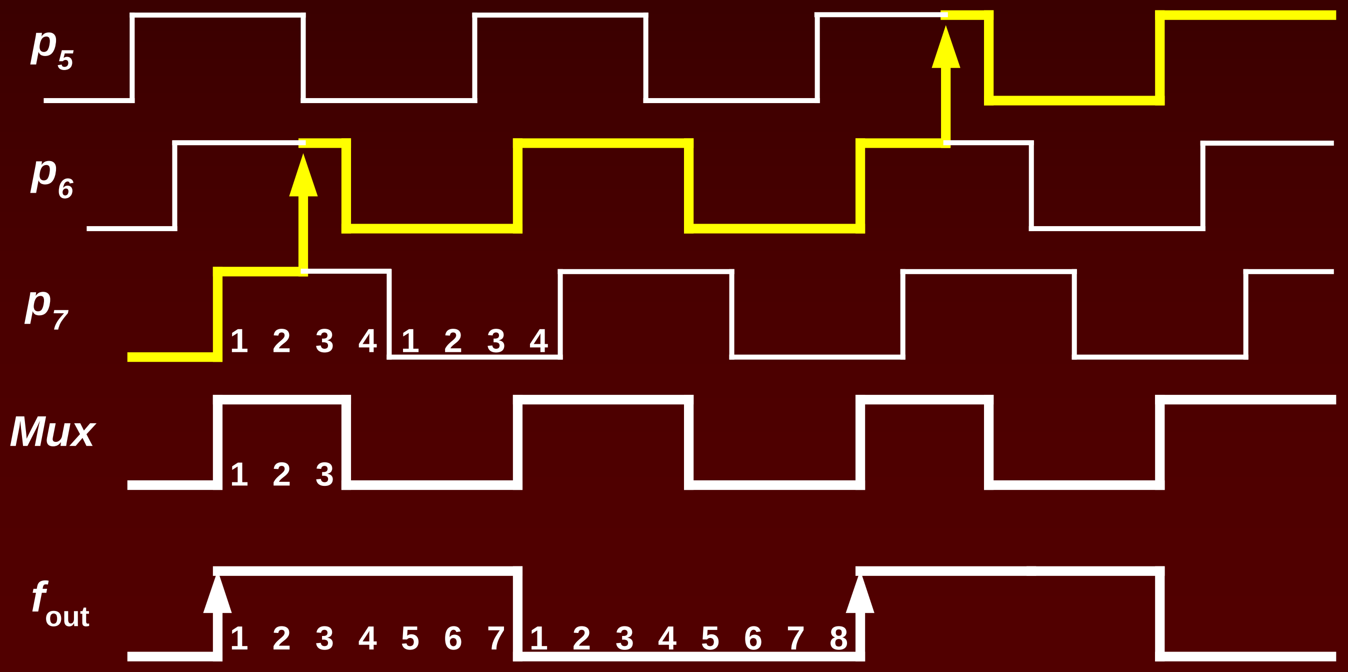
Total Current: 4 mA

15/16 Dual Modulus

Phase Switching Prescaler

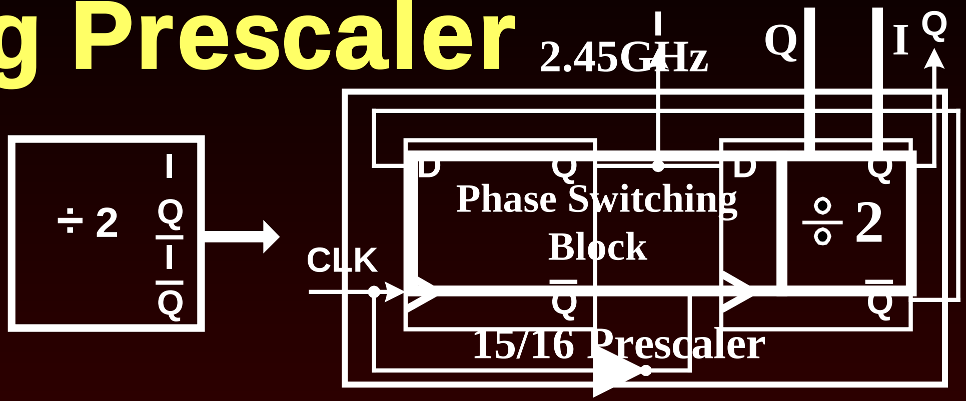
- Circuit Operation

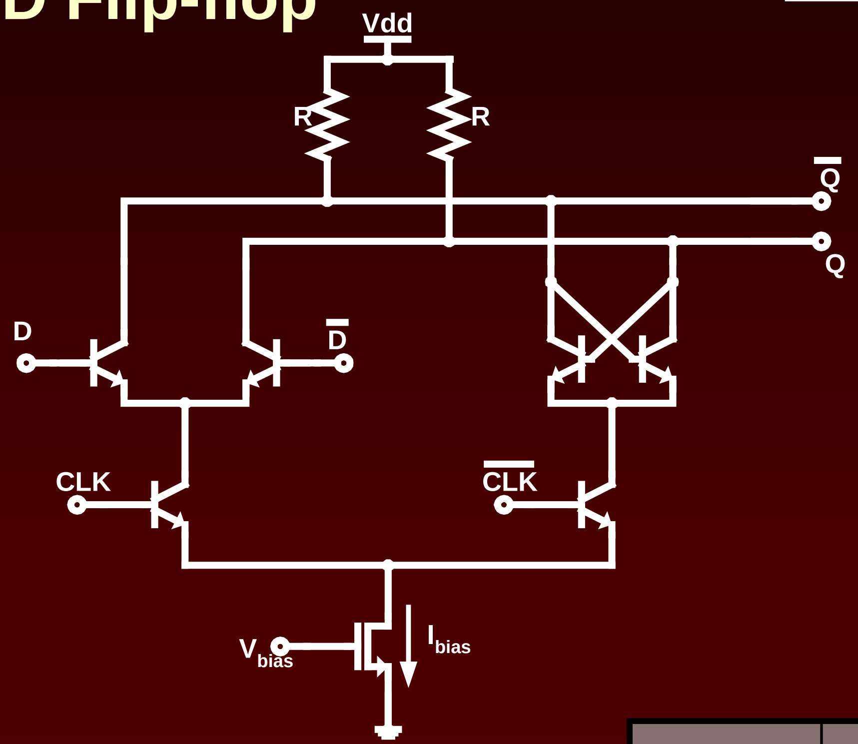


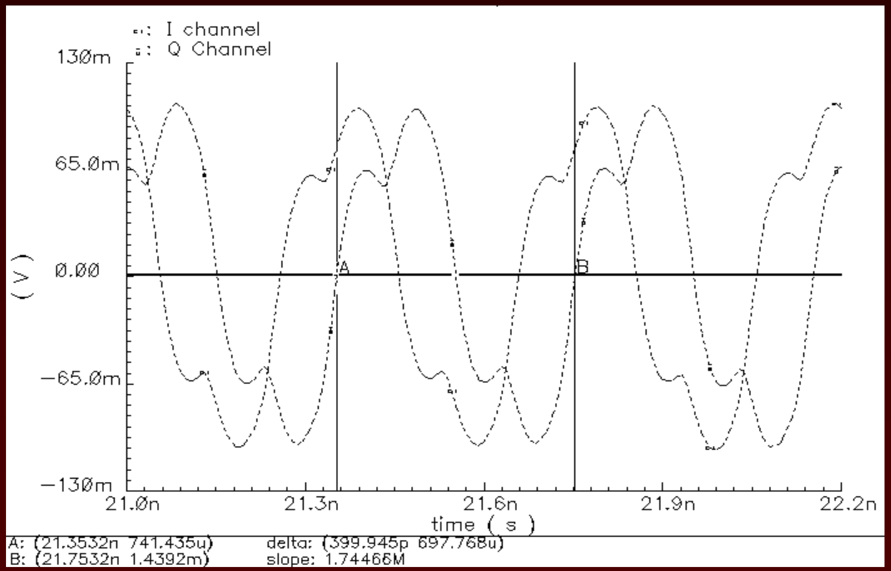


Phase Switching Prescaler

- **Implementation:**
  High Frequency
  D Flip-flop



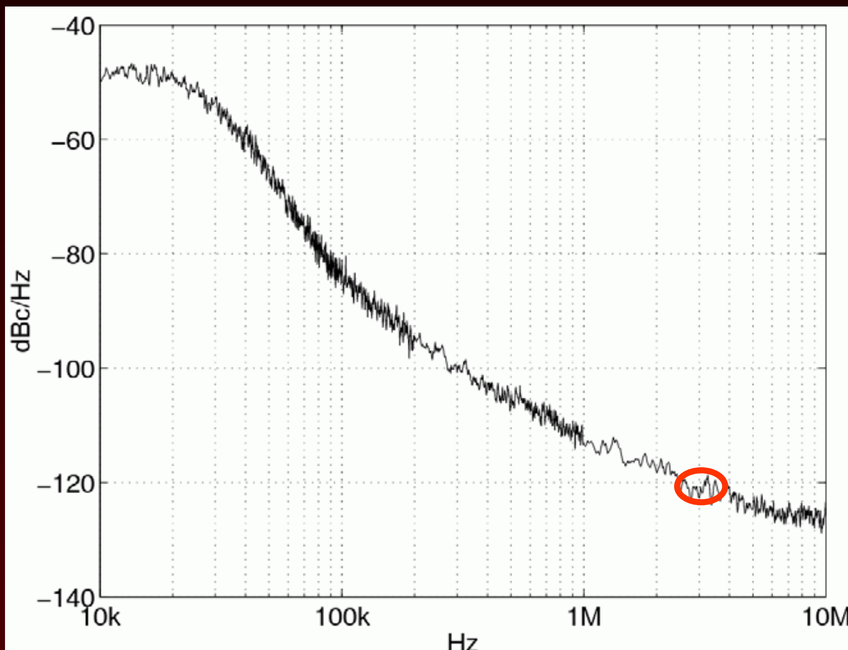




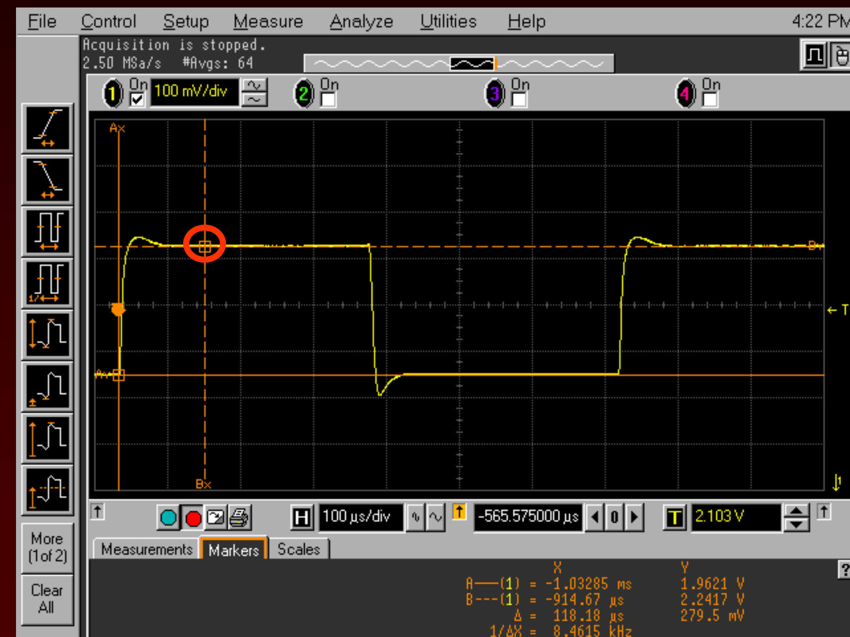
	1st stage	2nd stage	3rd stage
I_{bias}	500 μA	375 μA	250 μA
R	1 kΩ	1.3 kΩ	2 kΩ

Measurement Results

- Phase Noise



- Settling Time

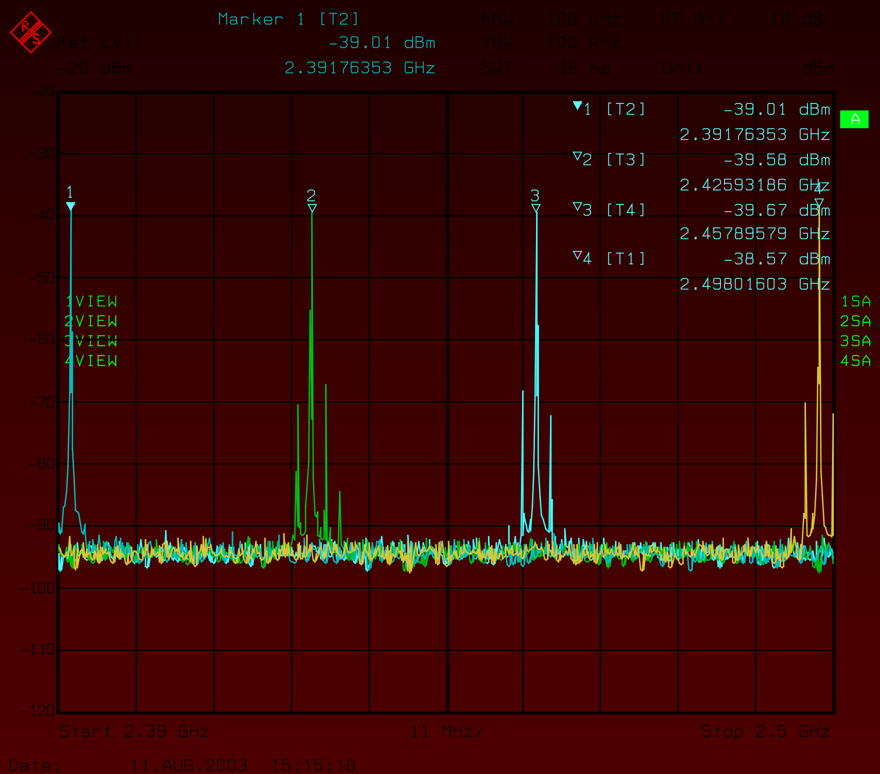


Phase Noise:
-124 dBc/Hz @ 3MHz

Settling time :
150 µs (220 µs spec)

Measurement Results

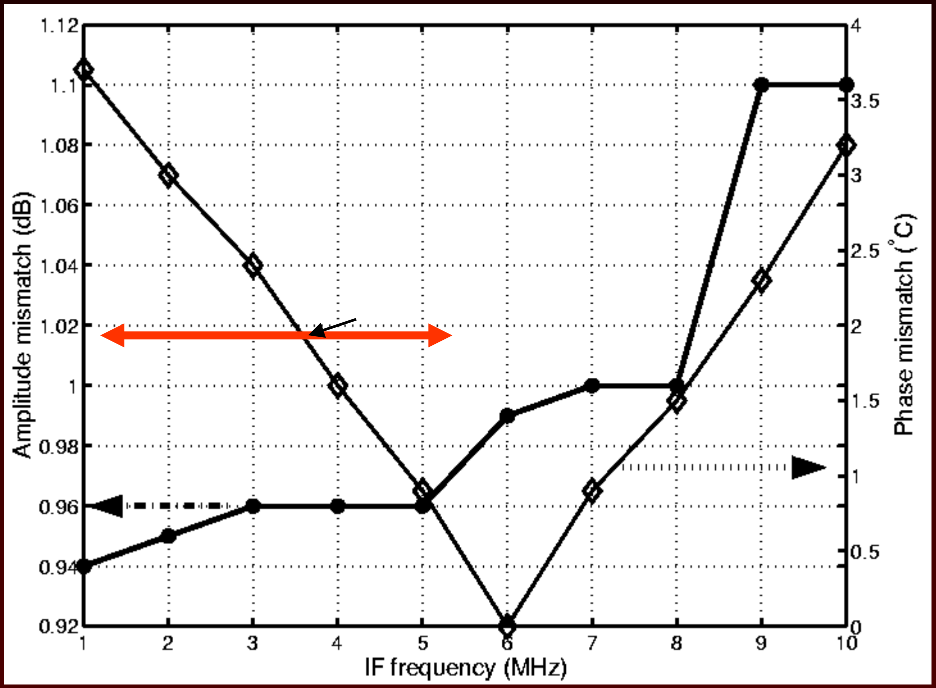
- Output Spectrum



Tuning Range:

2.391 – 2.498 GHz

- I/Q Mismatch



Worst case measurement

Phase error ≈ 3°

Magnitude error ≈ 1dB

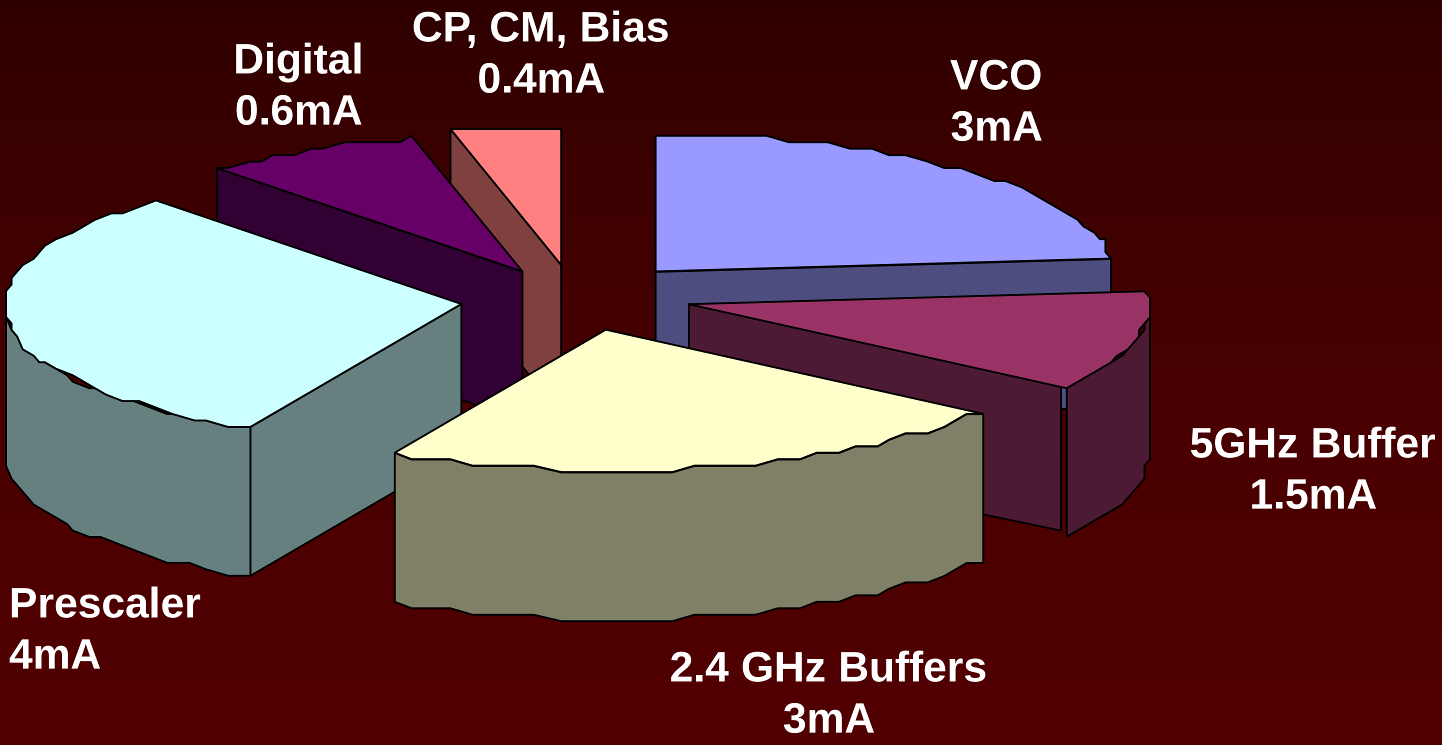
Summary of FS Testing Results

Parameter	Value	Units
Frequency Range	2400 - 2500	GHz
Phase Noise	-124	dBc @ 3MHz
Settling Time	150	μs
Reference Spur	-35	dBc
Power Consumption	31.25	mW
I/Q Mismatch Phase Amplitude	 < 3 < 1	 ° dB

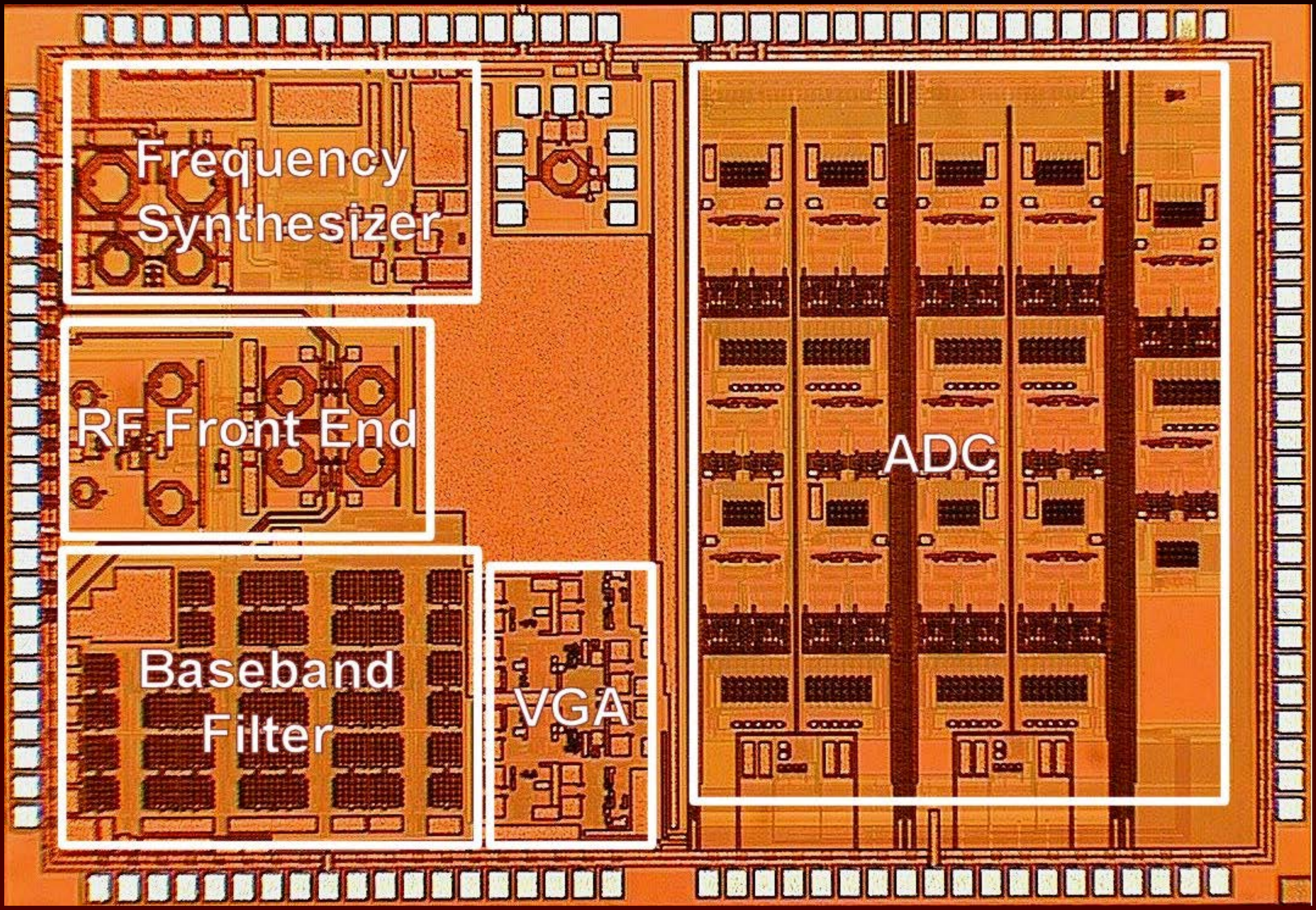
Summary of Testing Results

- Power Consumption Distribution

Total current consumption = 12.5mA with buffers



Die Micrograph



- Die Area: 21 mm^2
- Package: TQFP 128pins
- Synthesizer Area: 1.87 mm^2

A Multi-standard Frequency Synthesizer

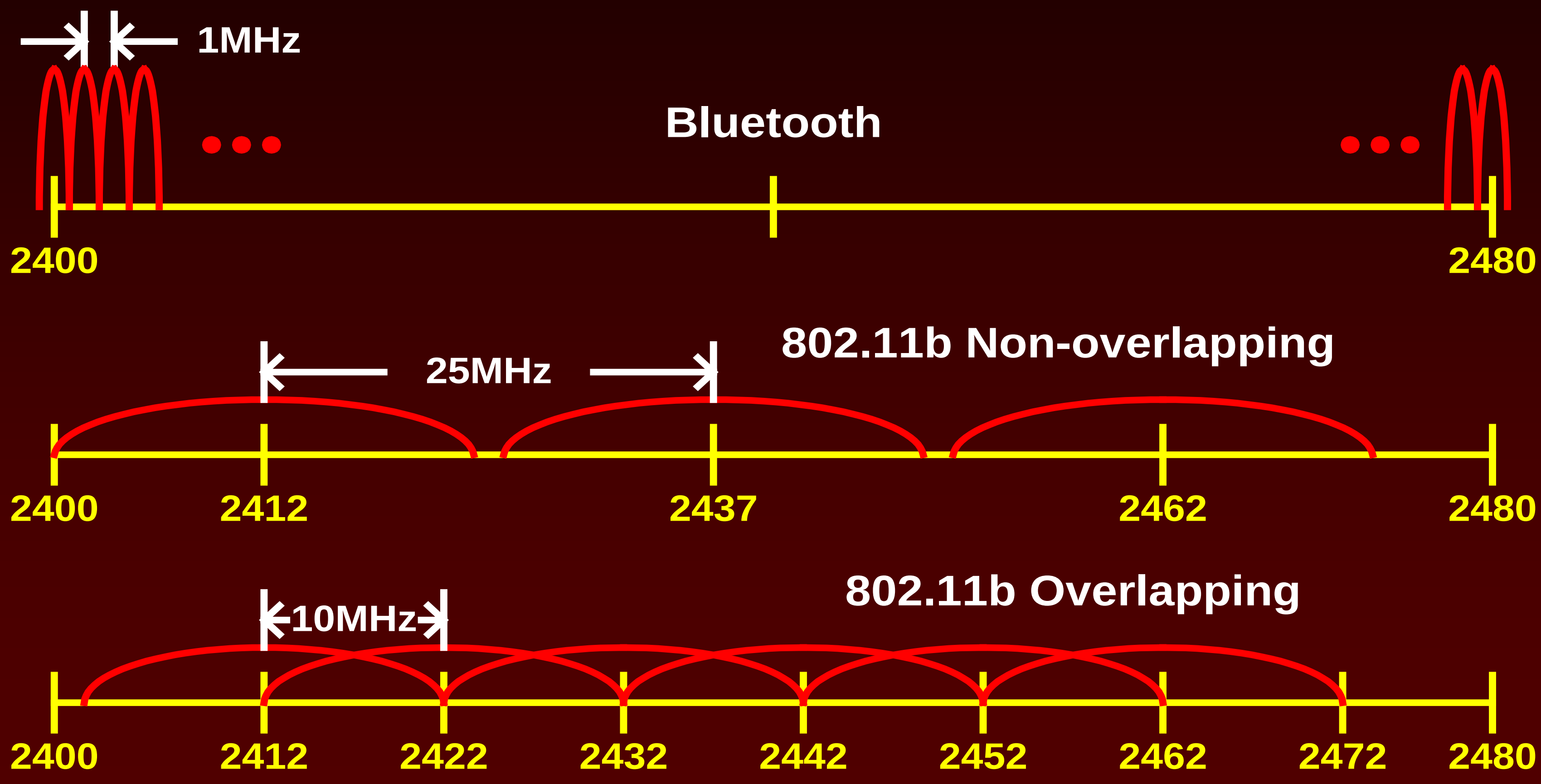
Sung Tae Moon

April 4, 2003

Bluetooth + WLAN 802.11b Specification

	Bluetooth	WLAN 802.11b
• Band	2.4~2.48	2.4~2.472 GHz
• Channel	1 MHz	5 MHz
• Settling	239 μs_{MAX}	220 μs_{MAX}
• Phase noise	−124 dBc @3 MHz	−126 dBc @25 MHz
• Accuracy	±75 kHz	±60 kHz

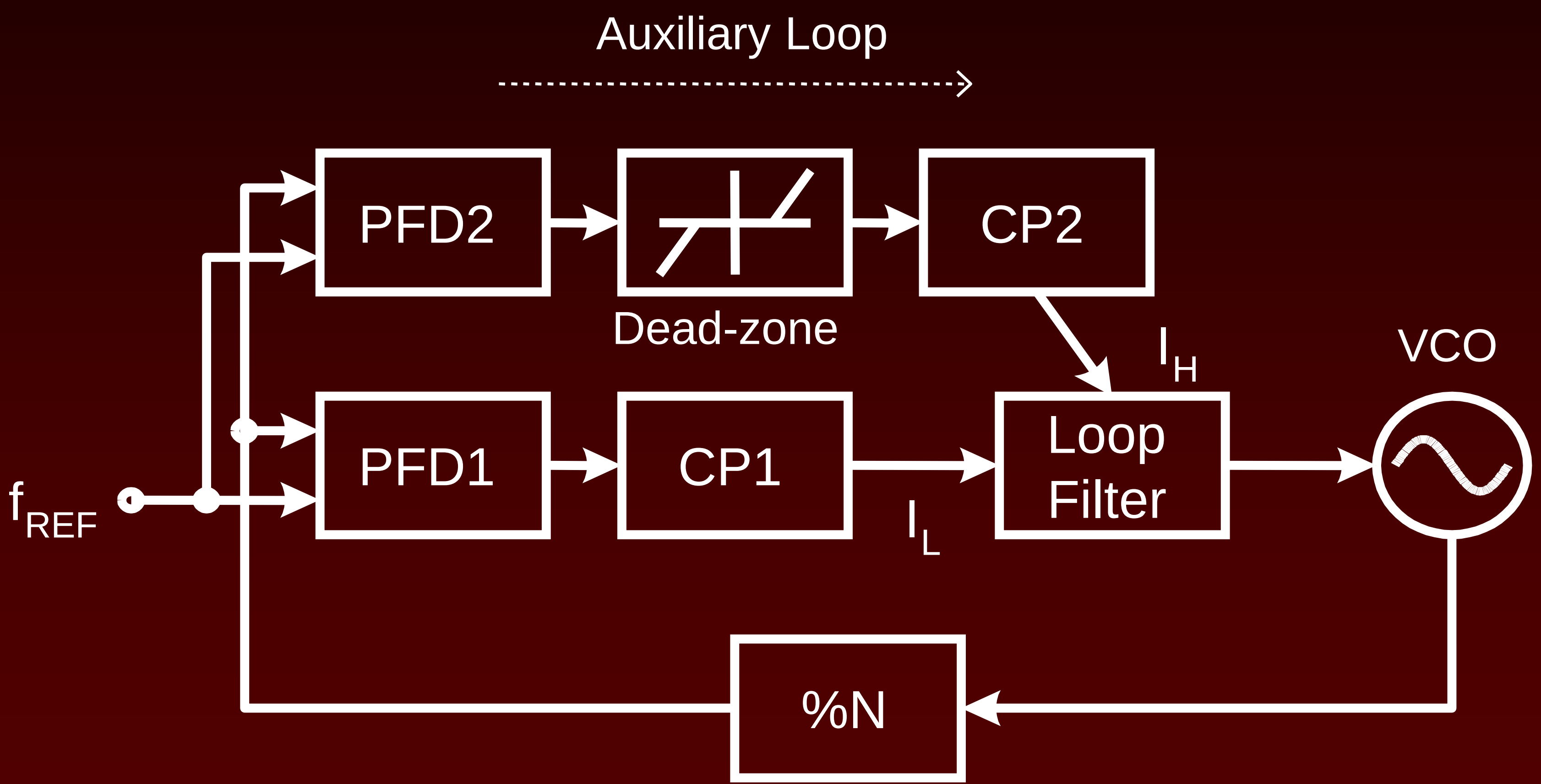
Bluetooth + WLAN 802.11b Specification



What's the Challenge?

- Limited loop bandwidth : 100 kHz
  - Results in slow settling
  - Adaptive dual-loop PLL
- Wide band VCO Necessary
  - Multi-frequency bands to allow for low K_{VCO} and wide tuning range
  - Automatic calibration to switch between bands

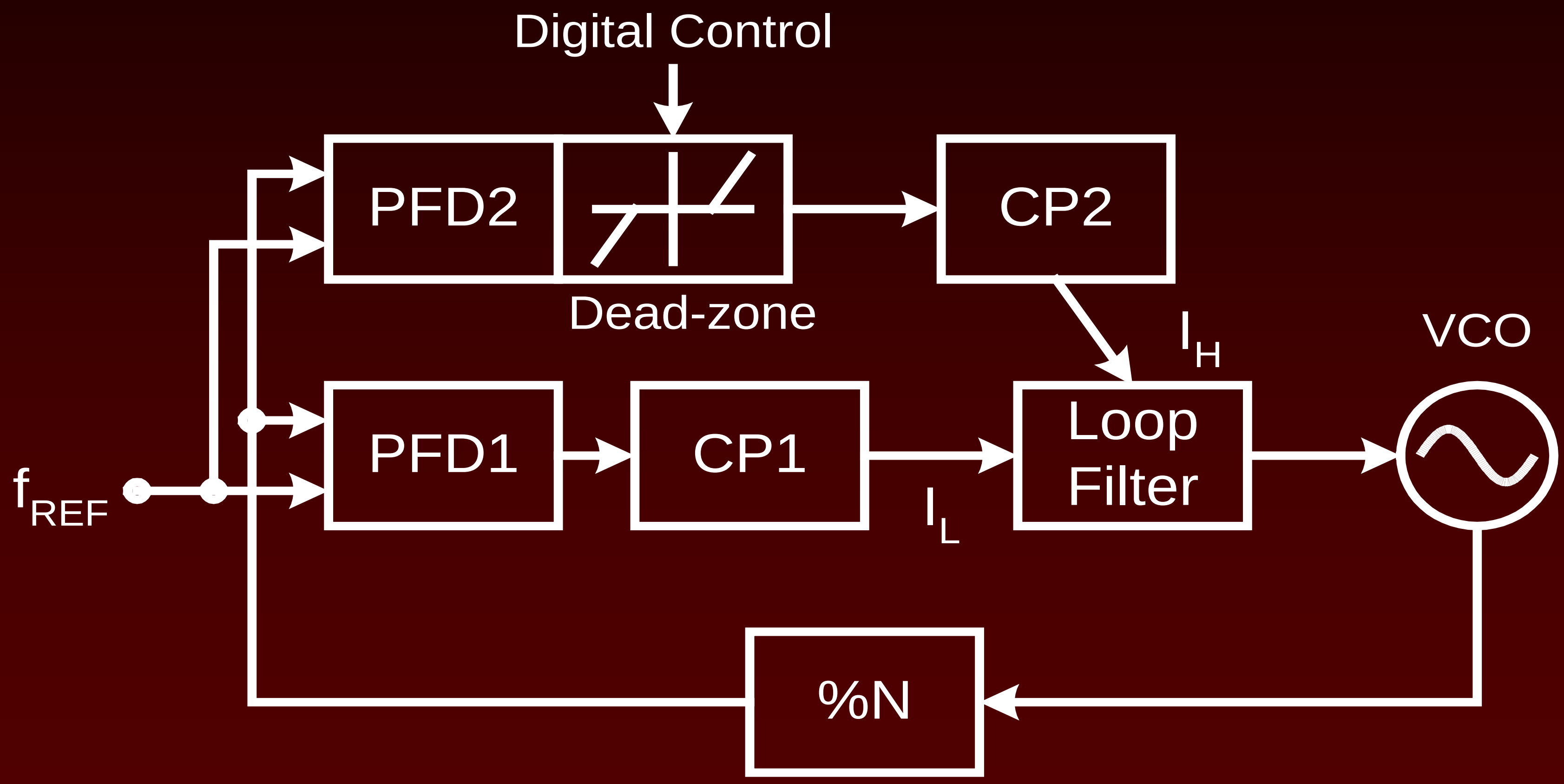
Adaptive Dual-loop PLL



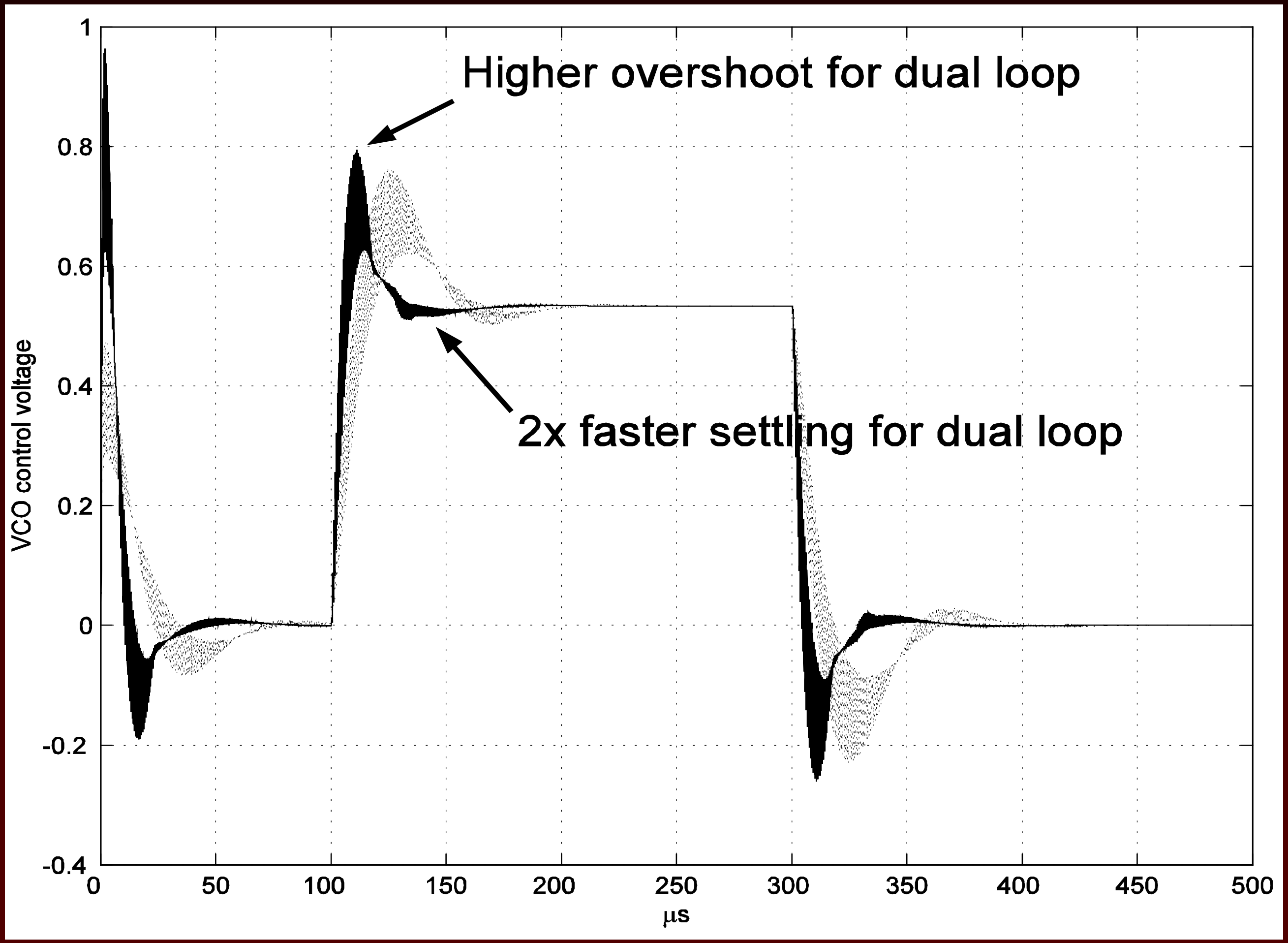
Adaptive Dual-loop PLL

- Less costly solution to limited loop-bandwidth problem
- Flexible Loop-bandwidth
- Glitch problem between bandwidth switching
- Smooth transition using dead-zone
- Improved dead-zone control

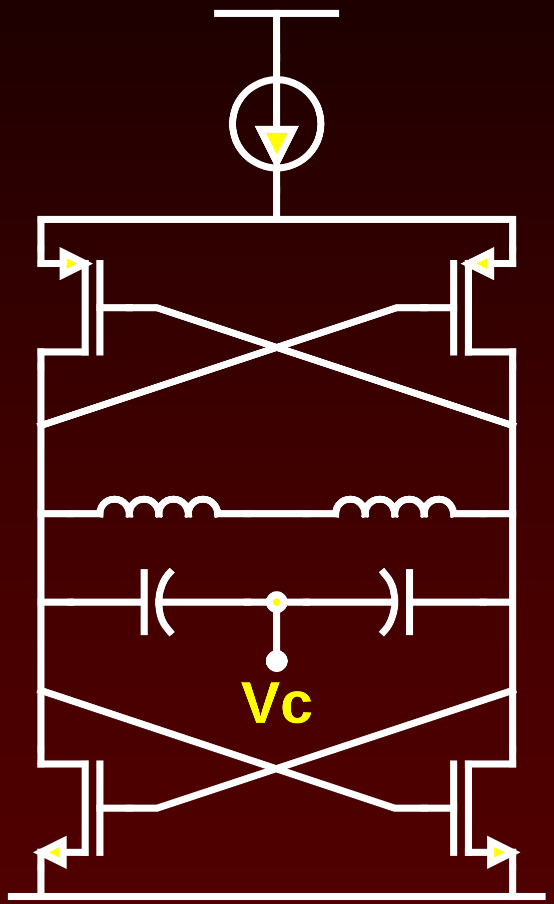
Dead-zone Control

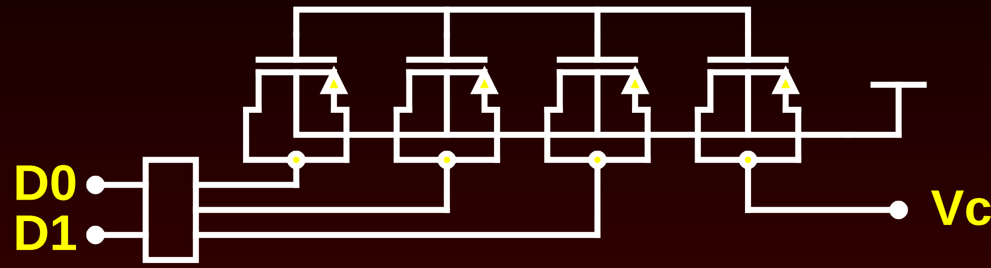


MATLAB simulation



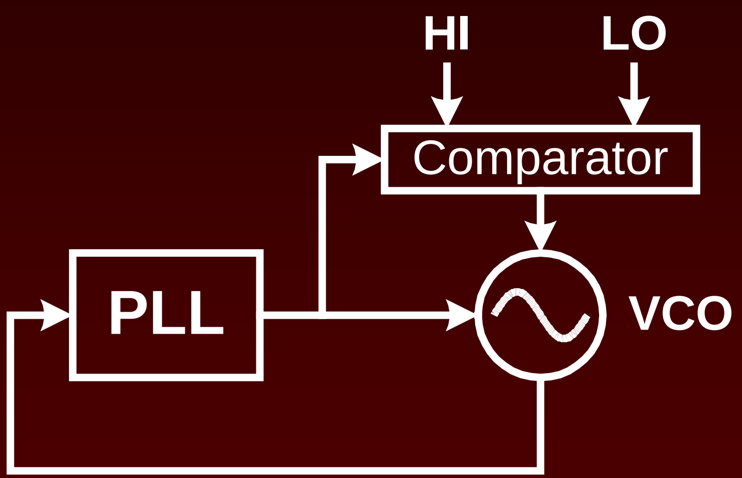
Wide-Band VCO with Calibration

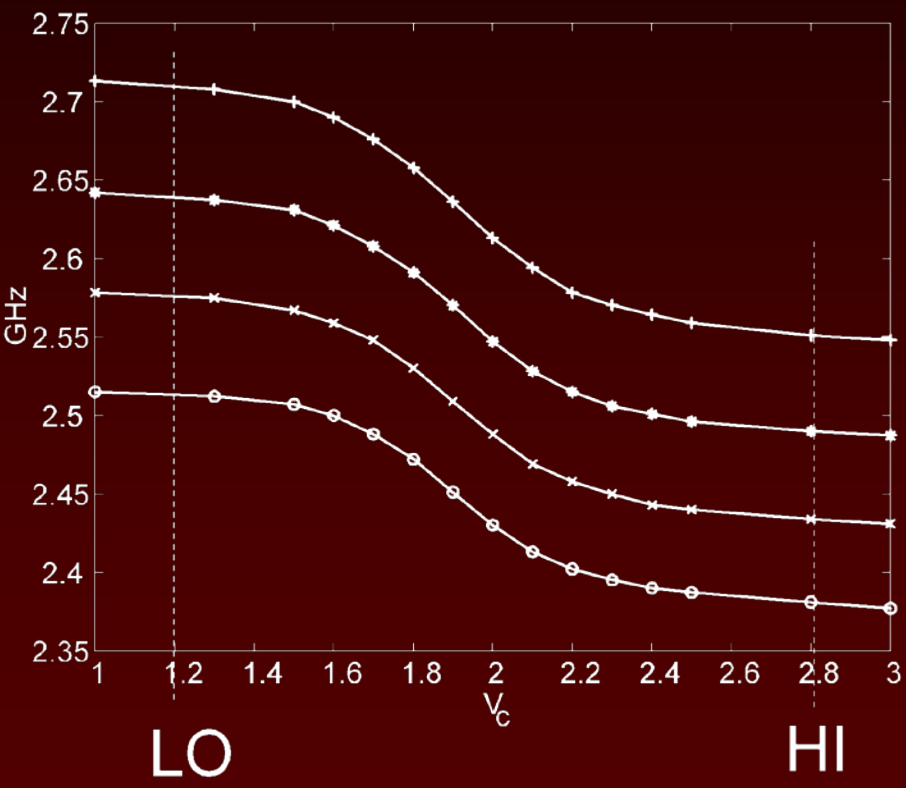




- Discrete capacitor array
  - Without array, tuning gain is too high
- With array, both wide band operation and low tuning gain are achieved
- Comparator loop for automatic calibration

Automatic Calibration





Next Time

- Fractional-N Frequency Synthesizers