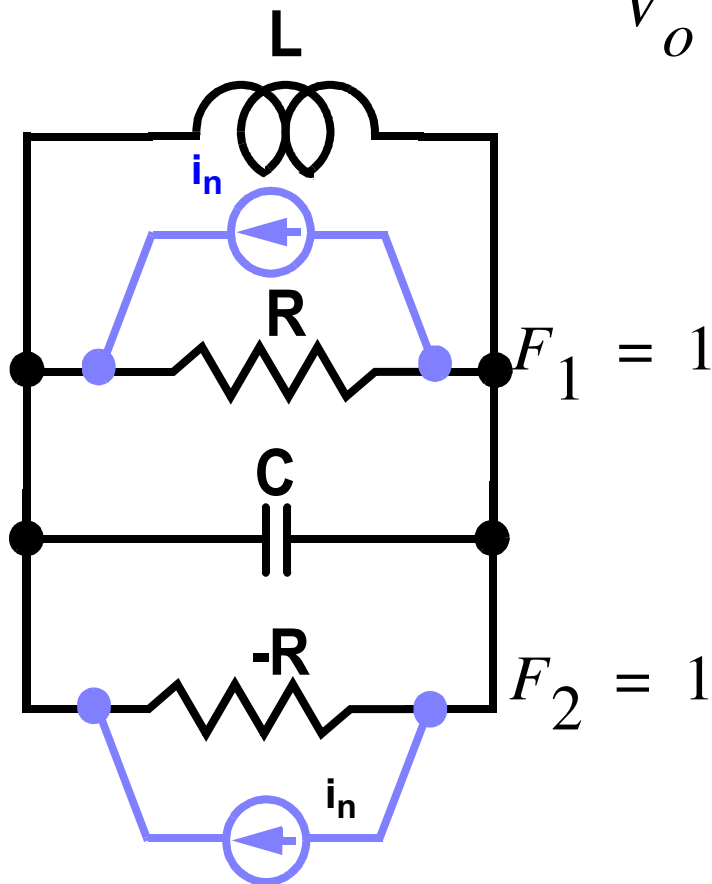


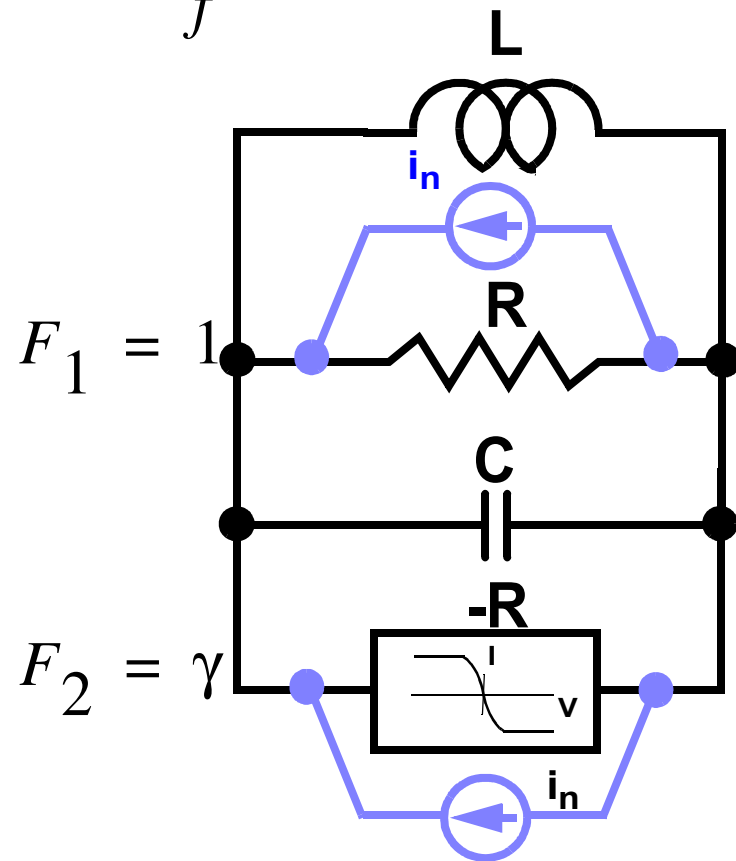
Fundamental Limits of Phase Noise

Leeson 1966

$$\mathcal{L}(f) = \frac{1}{V_o^2} \cdot \frac{kT}{C} \cdot \frac{\omega_o}{Q} \cdot \frac{2}{f^2} \cdot F$$



$$F = F_1 + F_2 = 2$$



$$F = F_1 + F_2 = 1 + \gamma$$

The Differential LC Oscillator

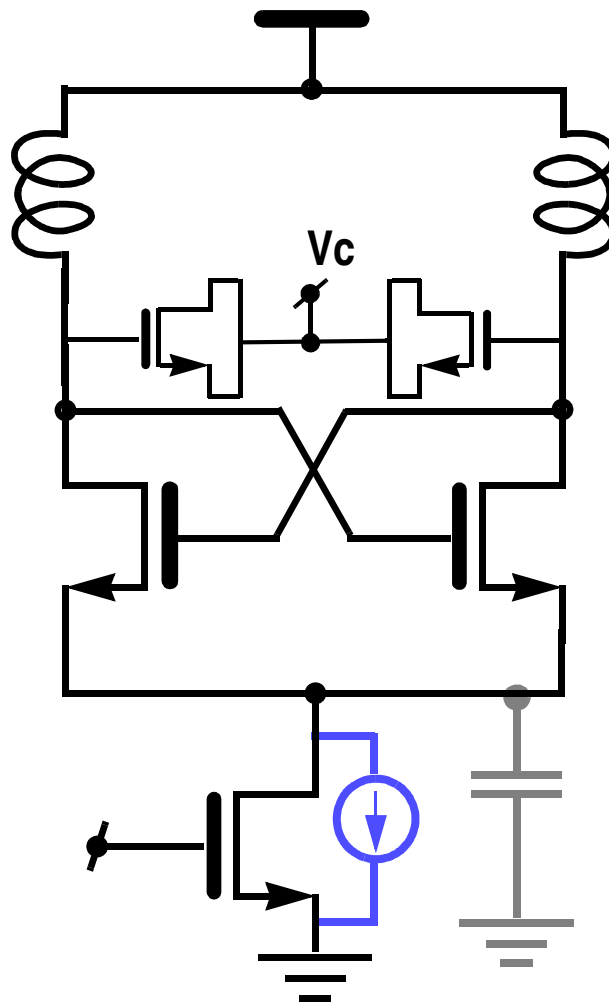
Rael 2000

$$F = 1 + \frac{4\gamma RI}{\pi V_o} + \gamma \frac{8}{9} g_{mbias} R$$

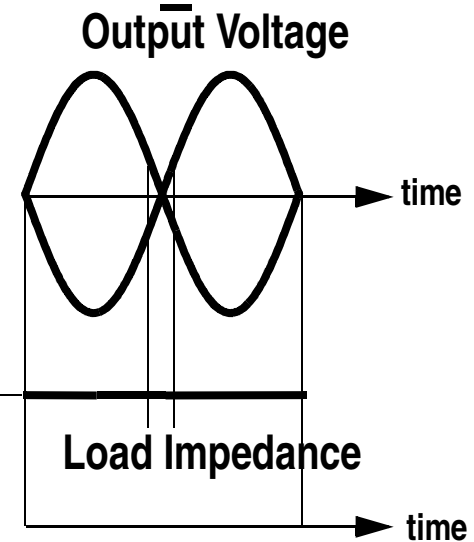
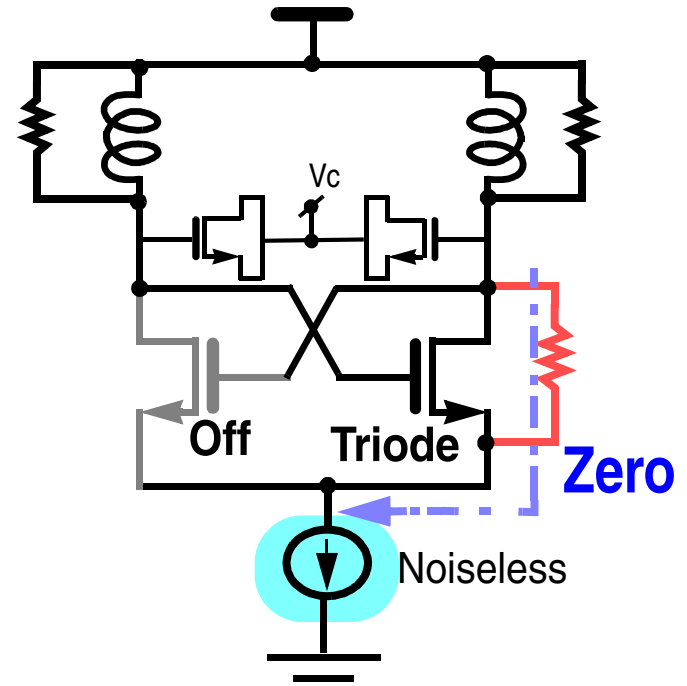
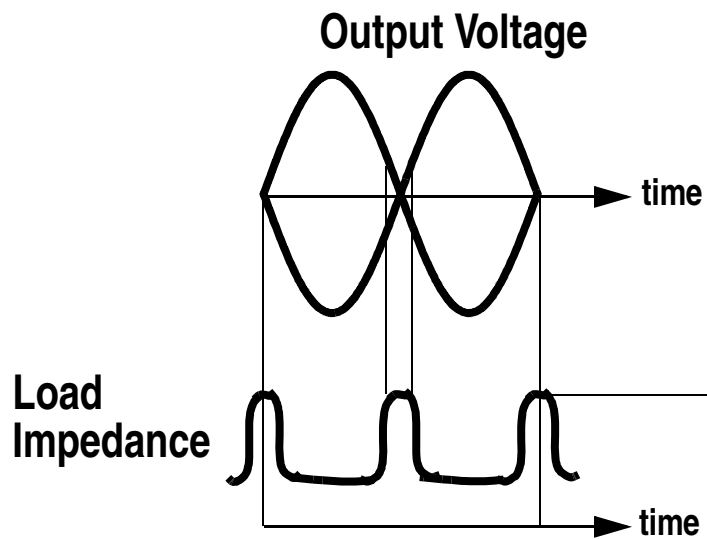
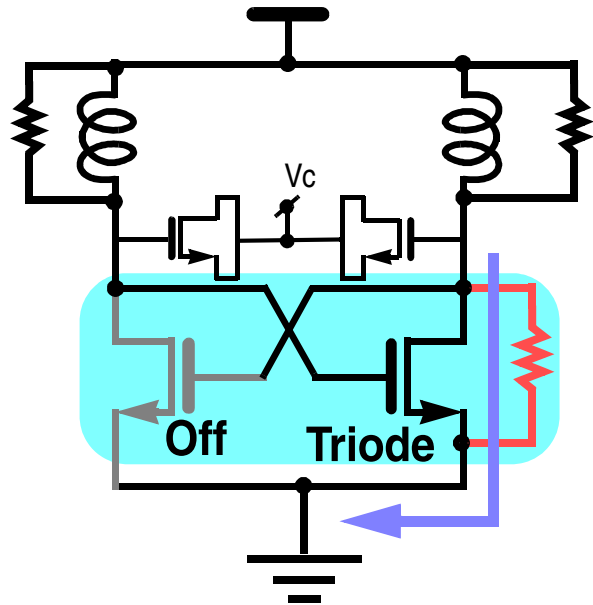
$$V_o = \frac{4RI}{\pi}$$

$$F_{min} = 1 + \gamma$$

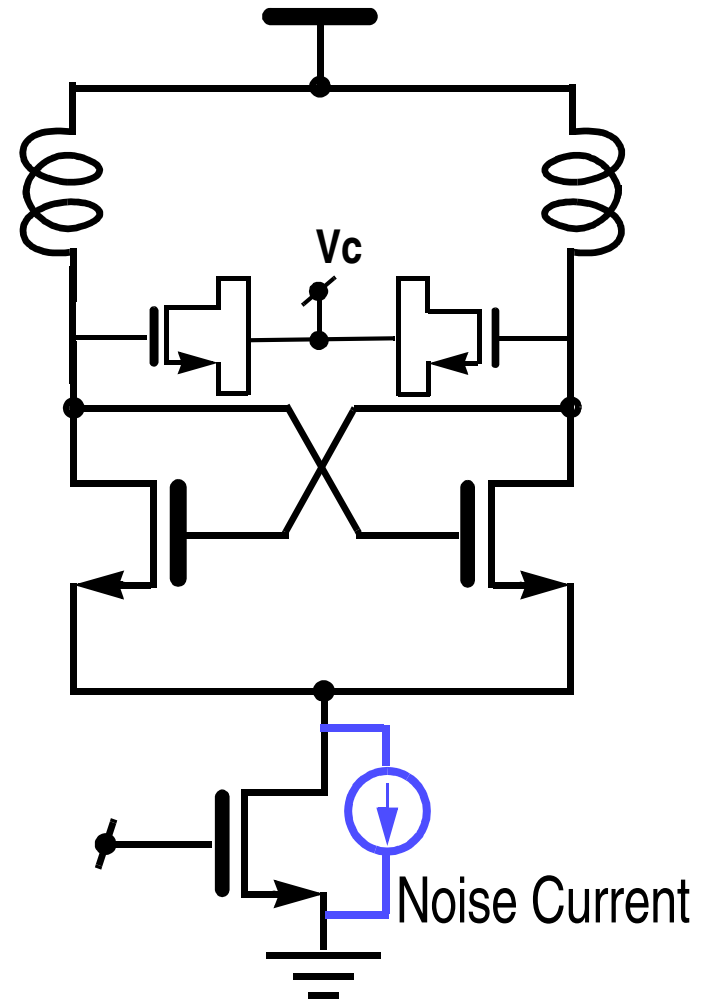
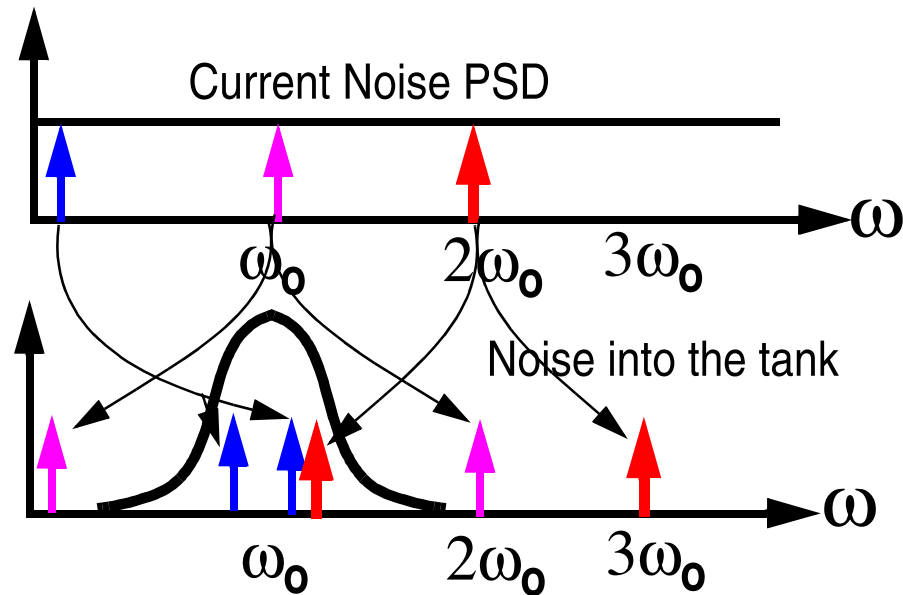
- ✓ **Amplitude is current-limited**
- ✓ **Need a noiseless current source**
- ✓ **Need a high impedance current source**



Role of the Current Source



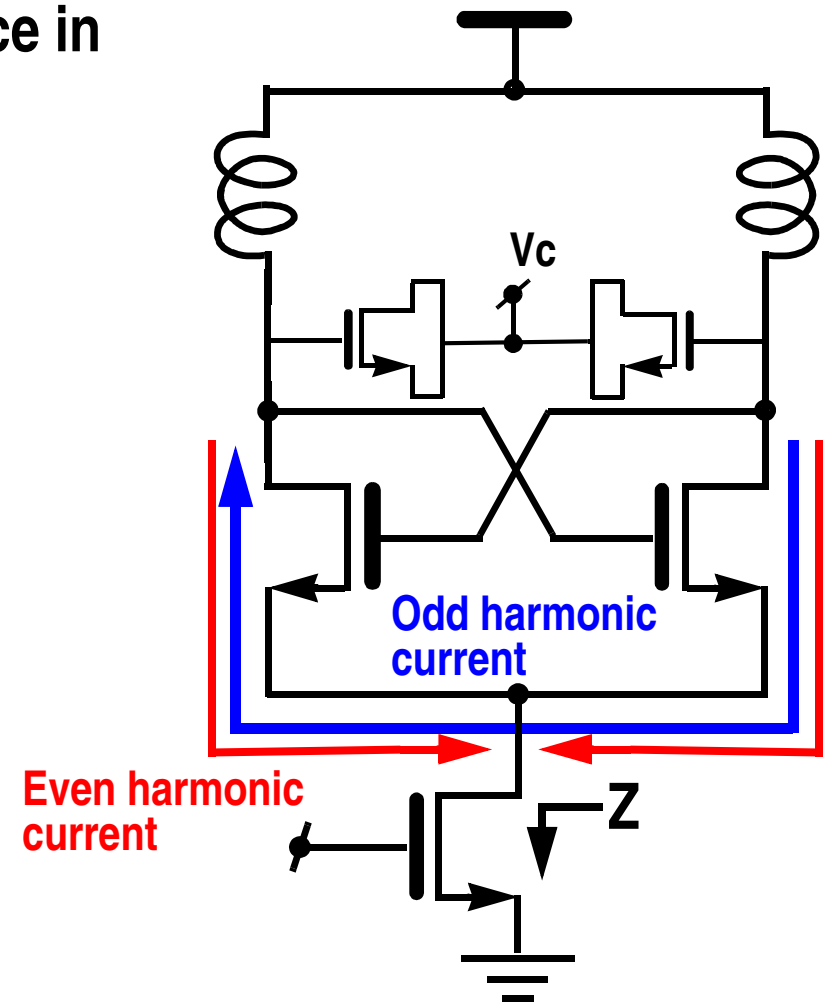
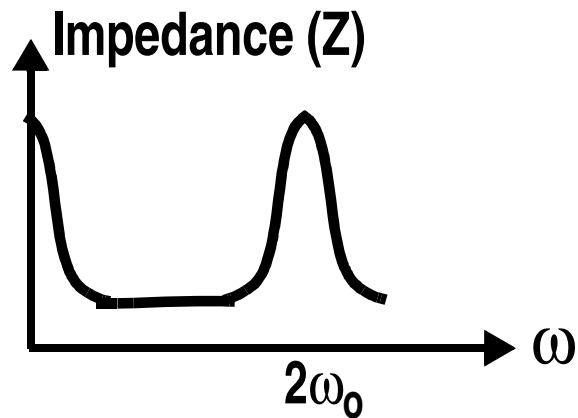
Phase Noise in Current-Biased LC Oscillators



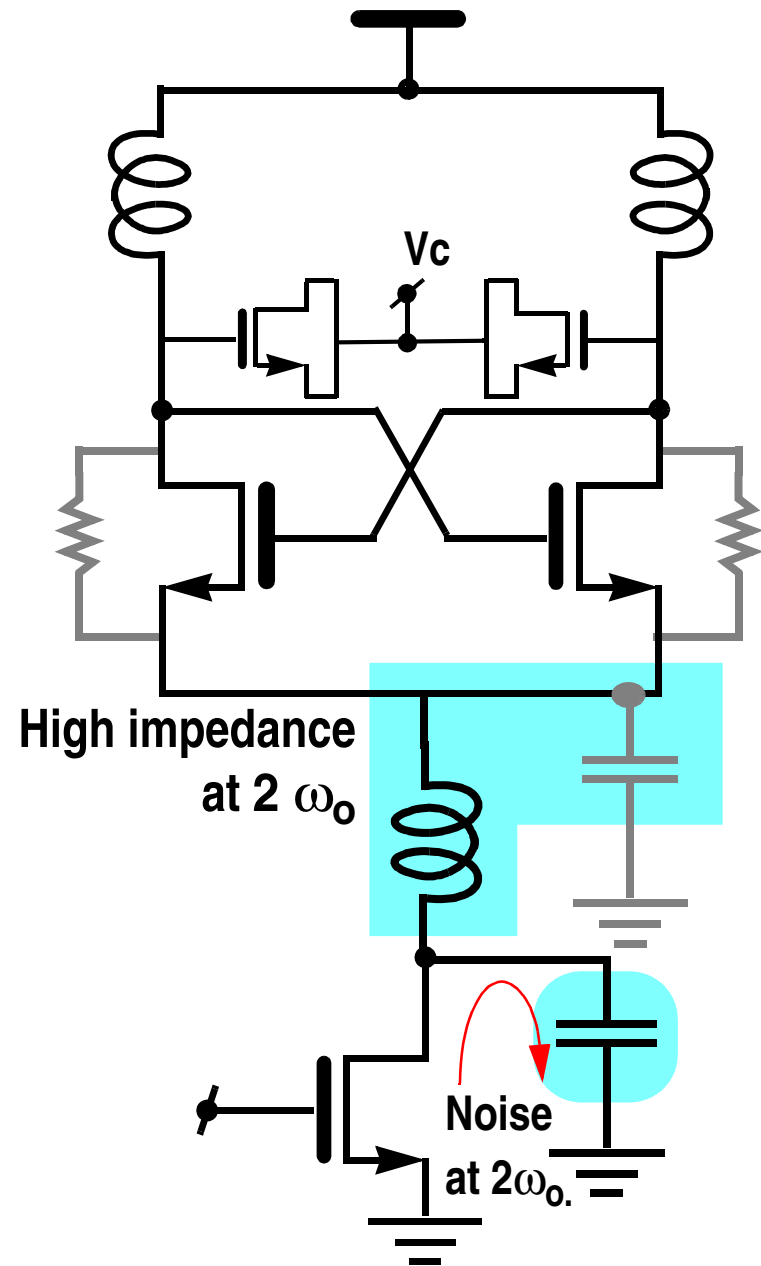
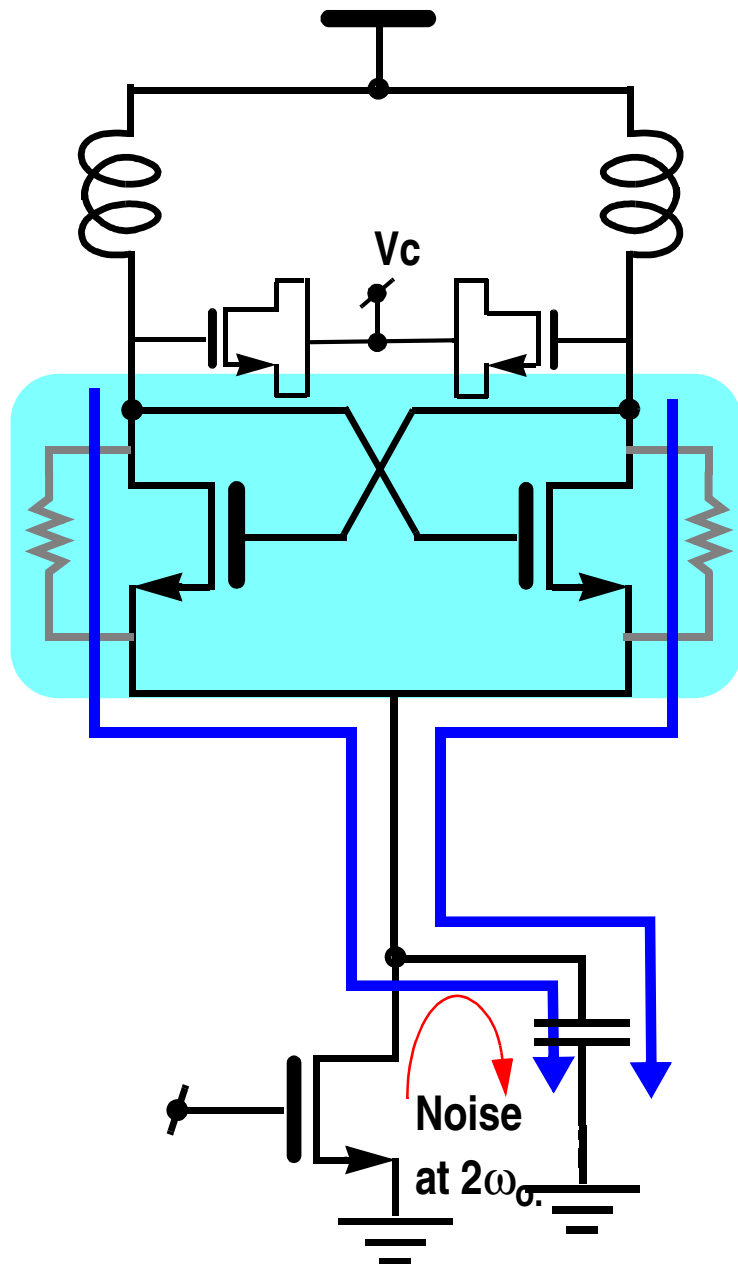
- ✓ Only noise at $2\omega_0$ creates phase noise
- ✓ Low frequency noise appears as amplitude noise

Phase Noise in Current Biased LC Oscillators

- ✓ Need high current source impedance in a narrow band around $2\omega_0$

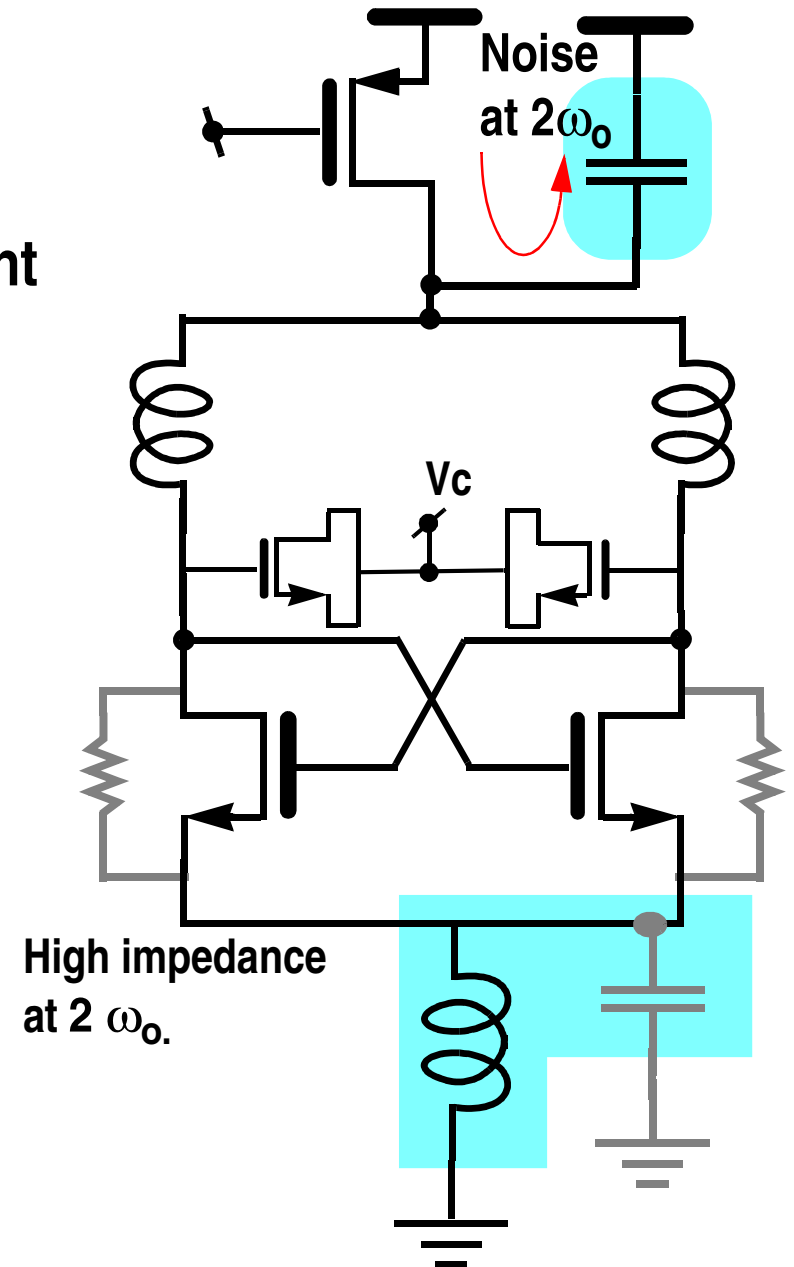


Tail-Biased VCO with Noise Filtering



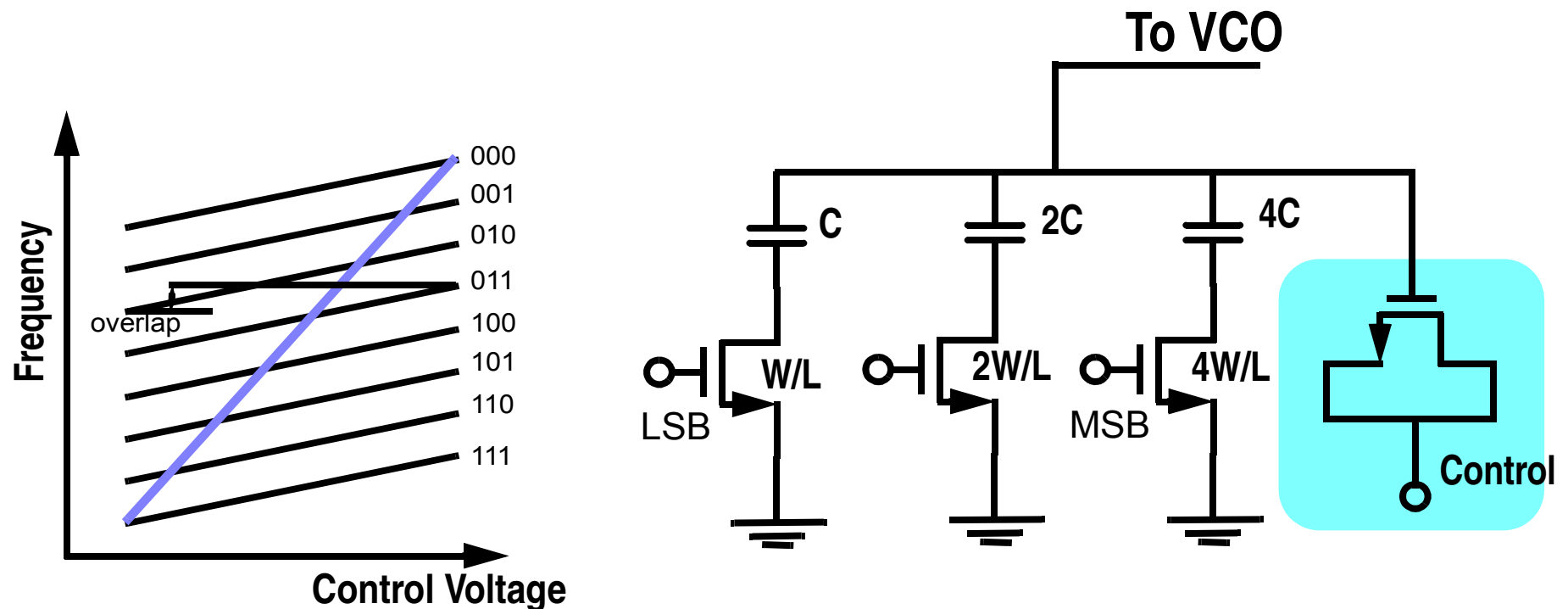
Top-Biased VCO with Noise Filtering

- ✓ Current source noise is shorted
- ✓ High impedance at common mode point
- ✓ Current source MOSFET can be scaled in size
- ✓ Immune to substrate noise.



Discrete Frequency Tuning

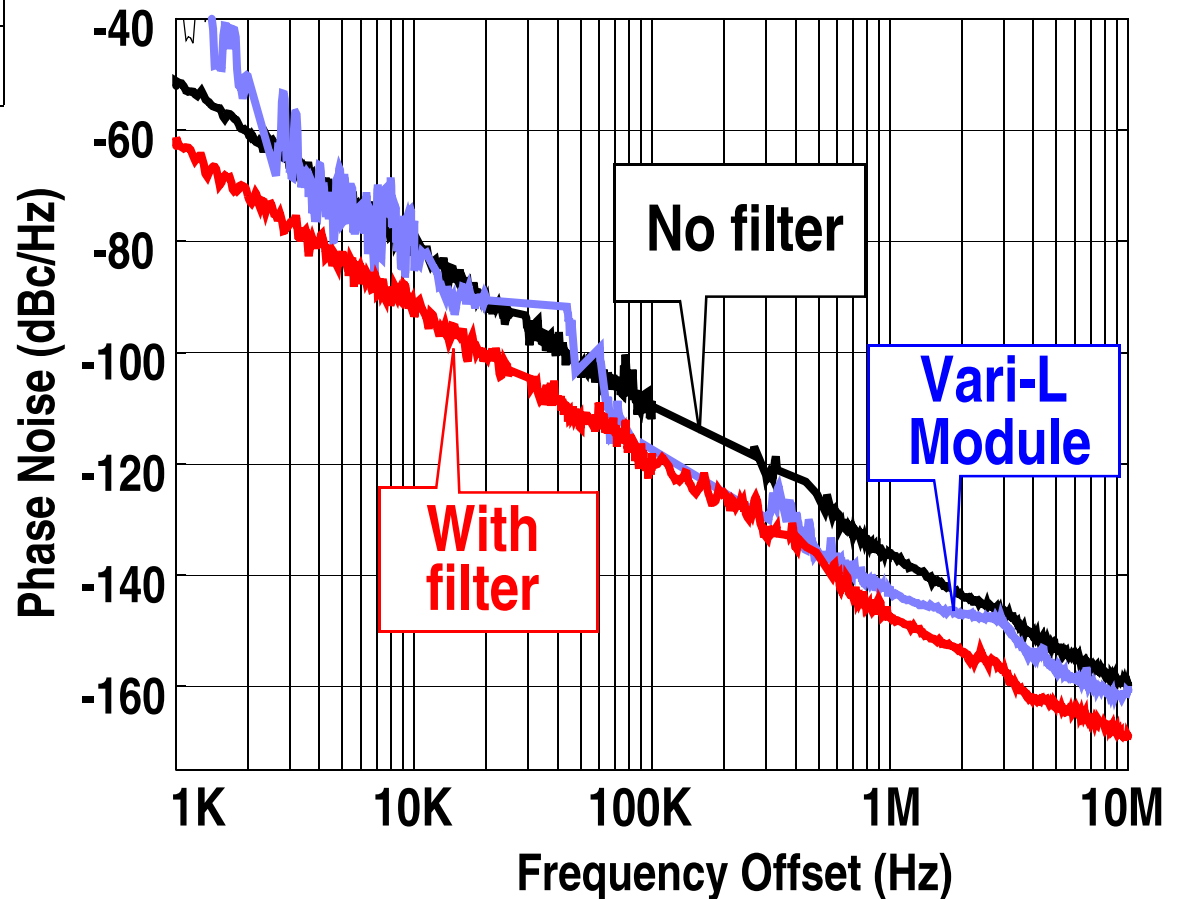
- ✓ Lower AM noise to FM conversion
- ✓ High quality switched-cap varactors with good layout



Measurement Results

Technology	0.35 μm CMOS
Supply	2.5 V
Current	3.7 mA
Tuning Range	20%
Frequency	1.2 GHz
$\mathcal{L}$ (3MHz)	-156 dBc/Hz

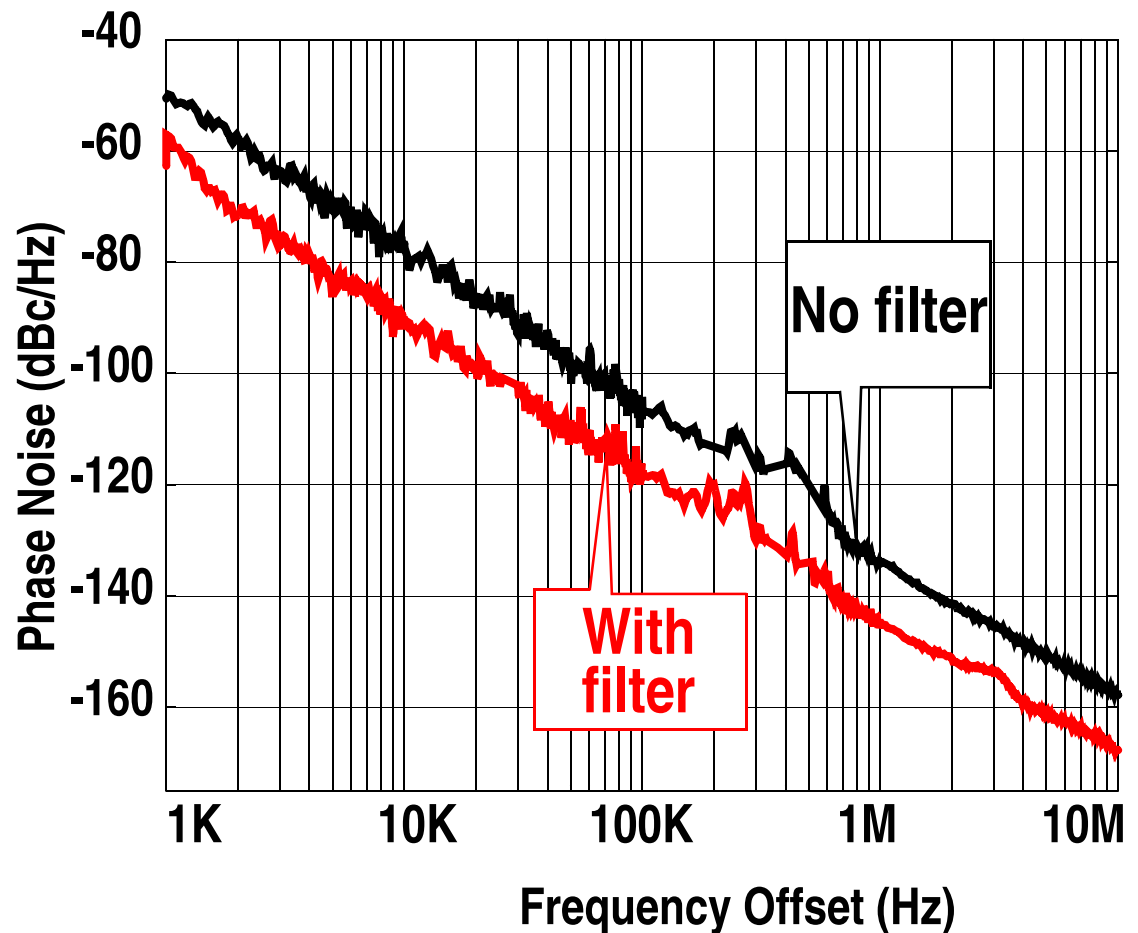
Tail-Biased VCO



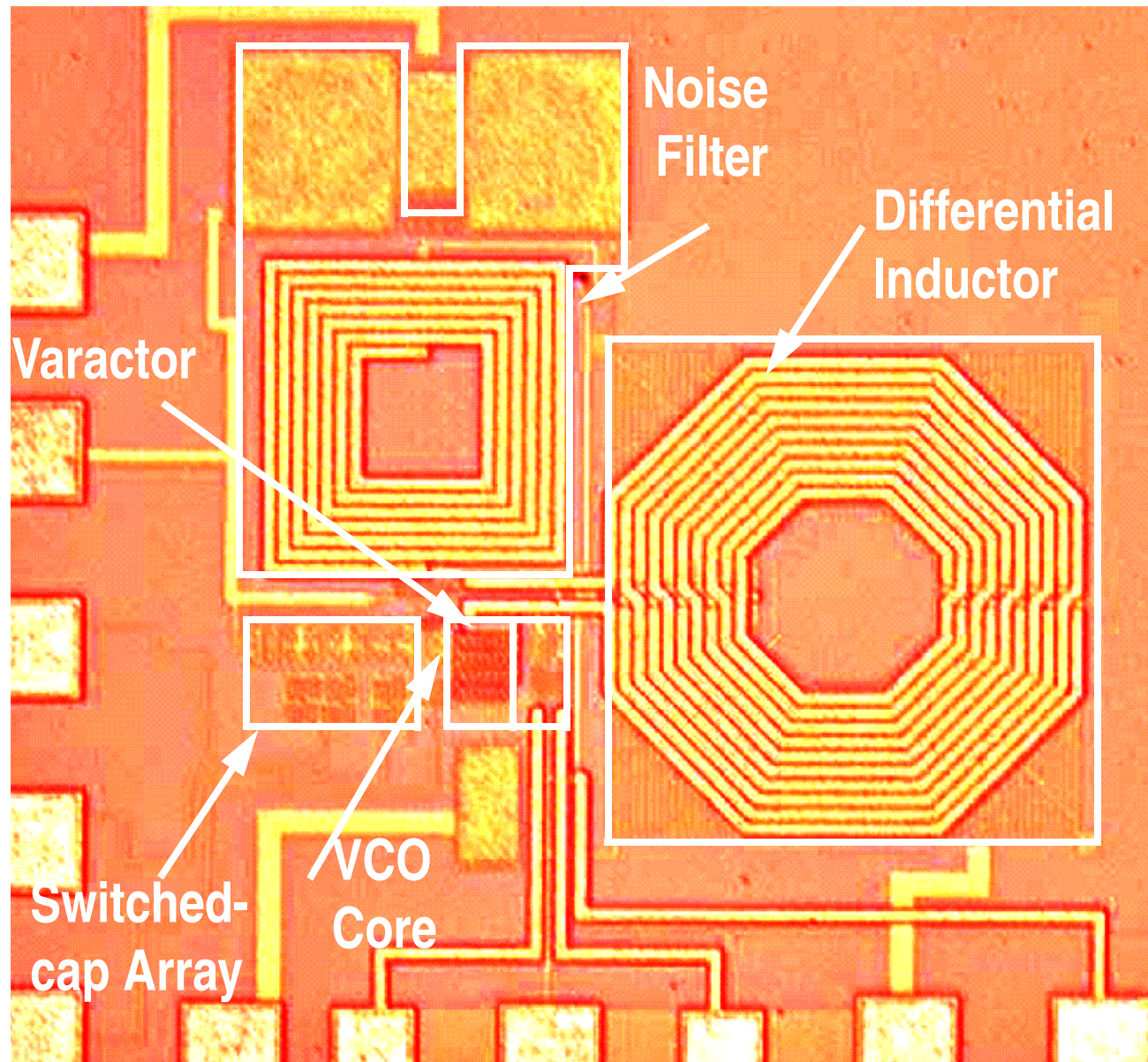
Measurement Results-II

Top-Biased VCO

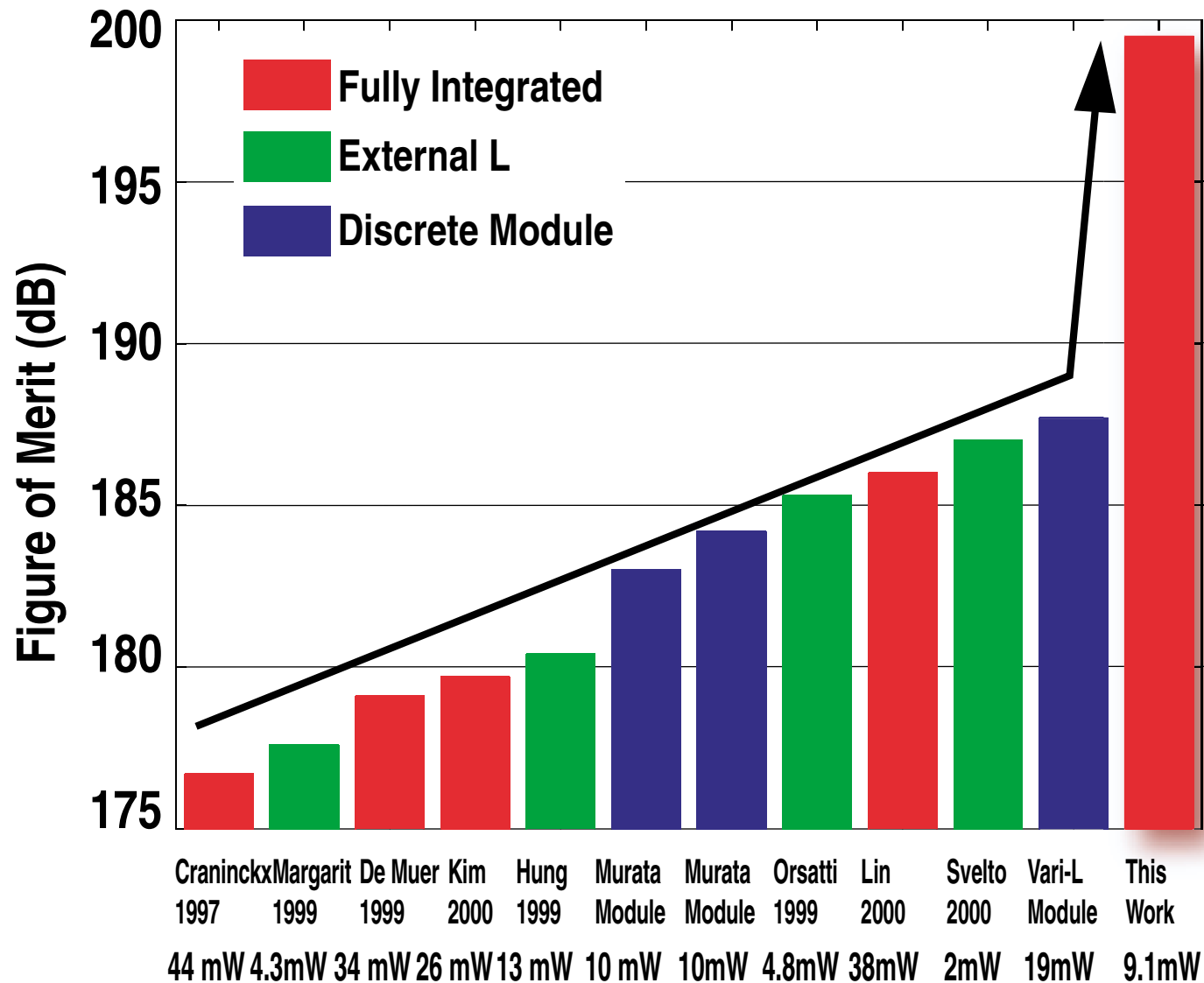
Technology	0.35 μm CMOS
Supply	2.5 V
Current	3.7 mA
Tuning Range	20%
Frequency	1.2 GHz
$\mathcal{L}$ (3 MHz)	-153.5 dBc/Hz



Die Photo



Comparison with State-of-the-Art VCOs



$$FOM = 10 \cdot \log \left(\left(\frac{f_o}{\Delta f} \right)^2 \cdot \frac{1}{\mathcal{L}(\Delta f) \cdot P} \right)$$

Conclusions

- ✓ Filter brings noise factor down to its fundamental minimum $1+\gamma$, ($\gamma=4/3$)
- ✓ Based on a physical understanding of phase noise mechanisms
- ✓ Extendable to other current-biased LC oscillators
- ✓ Using filter, a fully integrated CMOS VCO outstrips the FoM of commercial discrete VCO modules

Another Example

Technology	0.35 μm CMOS
Supply	2.7 V
Current	4 mA
Frequency	2.1 GHz
$\mathcal{L}$ (15 MHz)	-148 dBc/Hz

