A 1.4-GHz 3-mW 0.5-μm CMOS LC Low Phase Noise VCO Using Tapped Bond Wire Inductors

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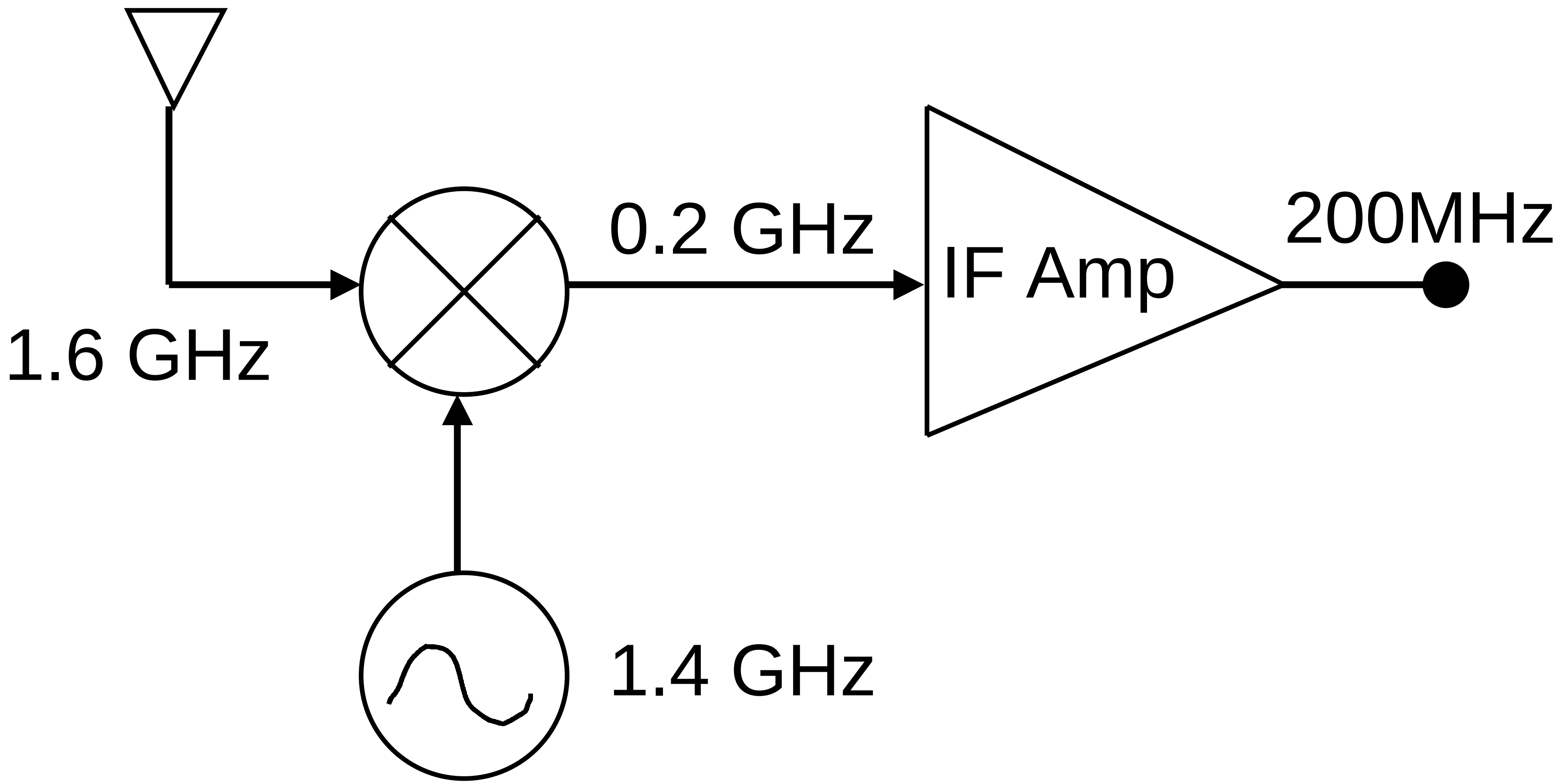
Outline

- Goals
- Approach
- Circuit
- Results

Goals of Design

- GPS - 1.575 GHz, IF=200MHz
- Low Power
- Minimum Phase Noise
- Tunable
- Reasonable Area

200 MHz IF Frequency for GPS



Ring Oscillator vs. LC Oscillator

Ring Oscillator: Dissipates all stored energy each cycle

→ High power dissipation

Large tuning range

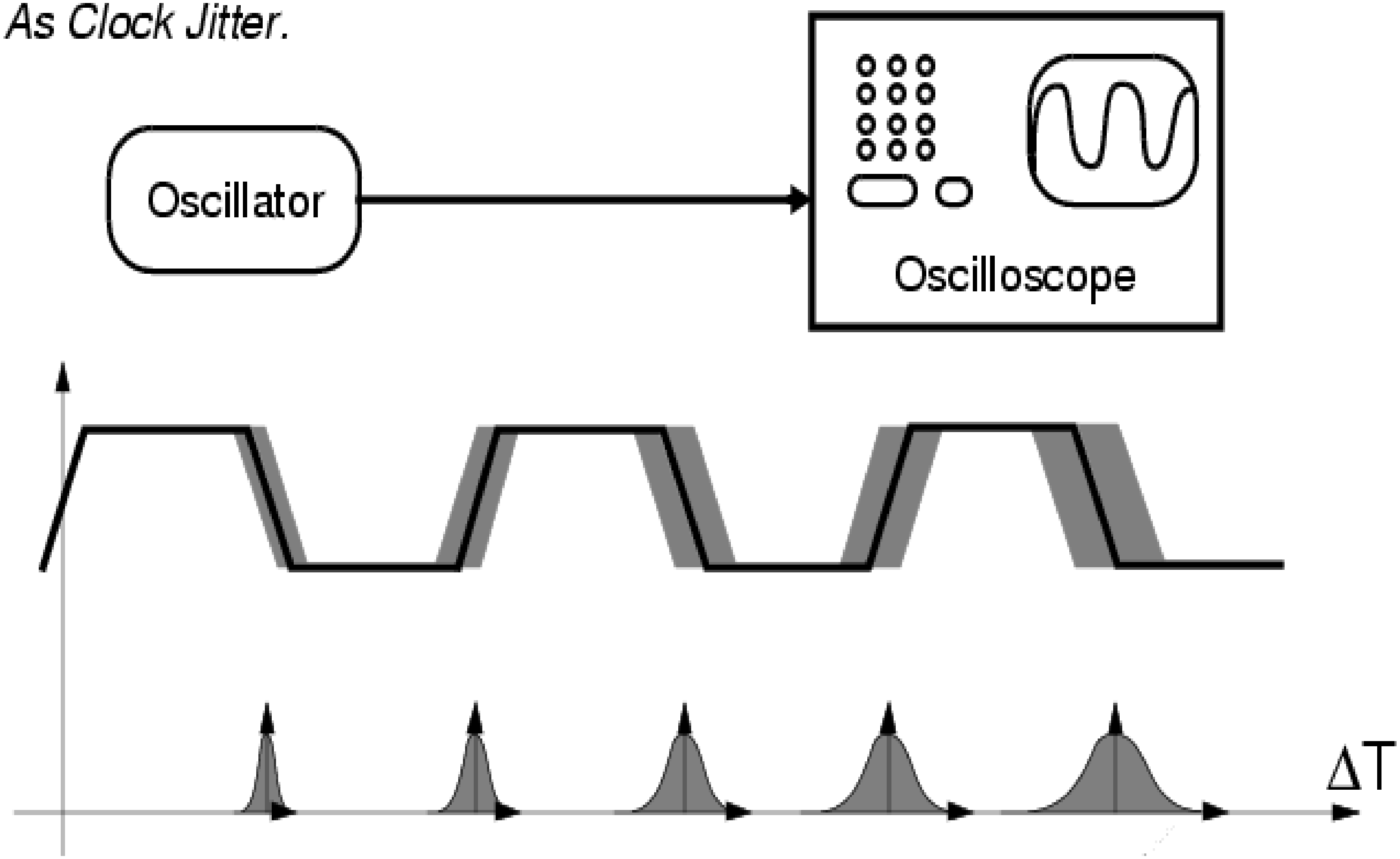
LC Oscillator: Dissipates 1/Q of the energy in the resonant tank

→ Lower power dissipation

$$Q = \frac{\text{Stored energy}}{\text{Dissipated energy}} * 2\pi$$

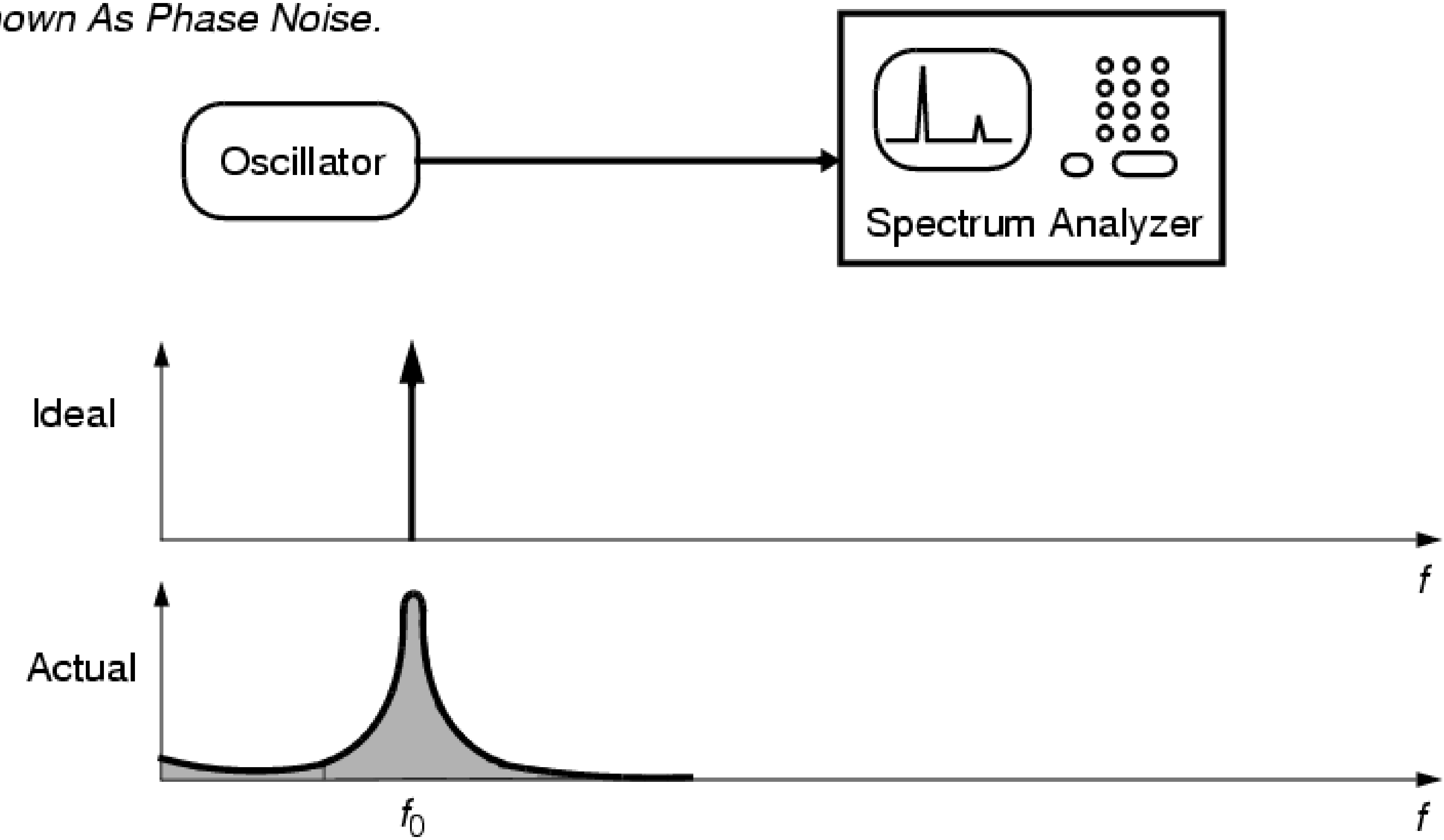
Frequency Instability - Time Domain

Known As Clock Jitter.

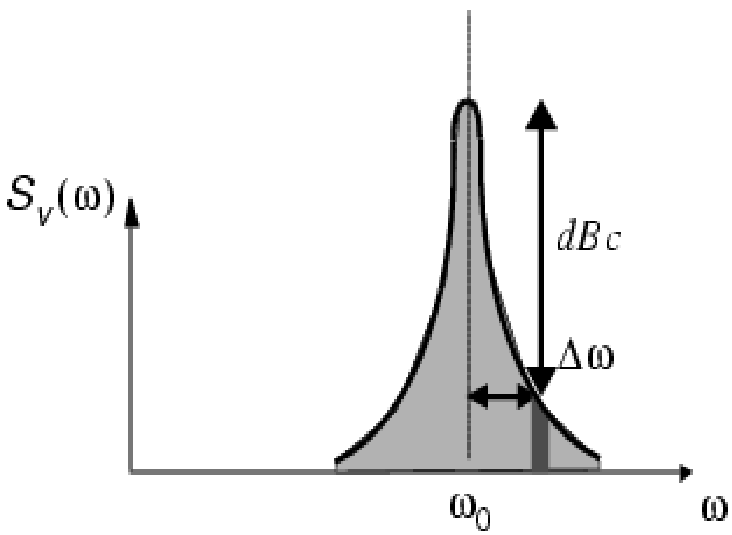


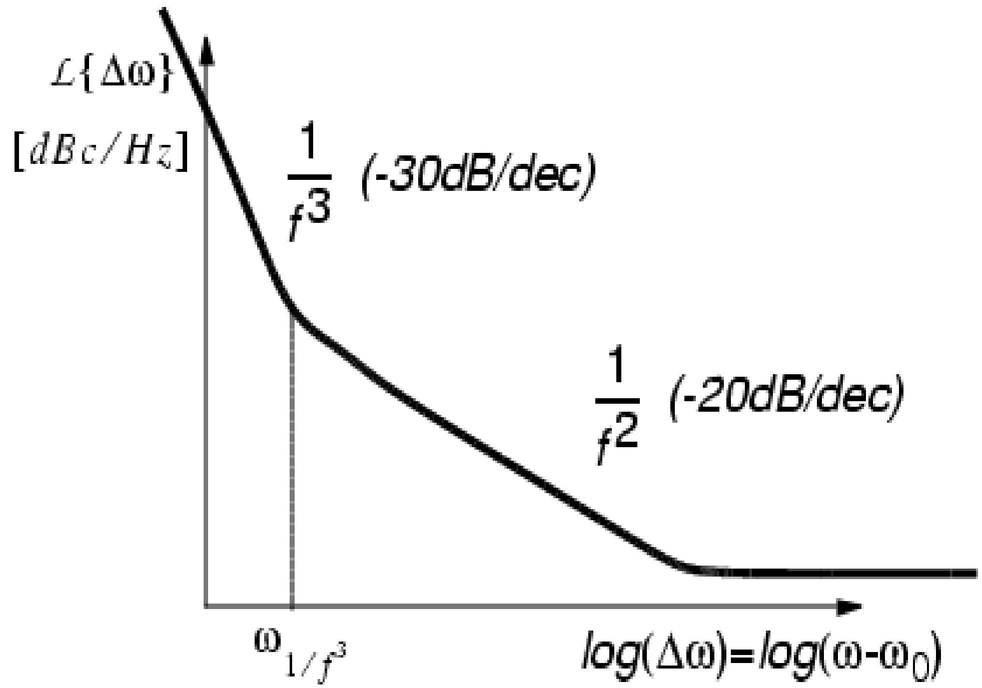
Frequency Instability - Freq Domain

Known As Phase Noise.



Units of Phase Noise

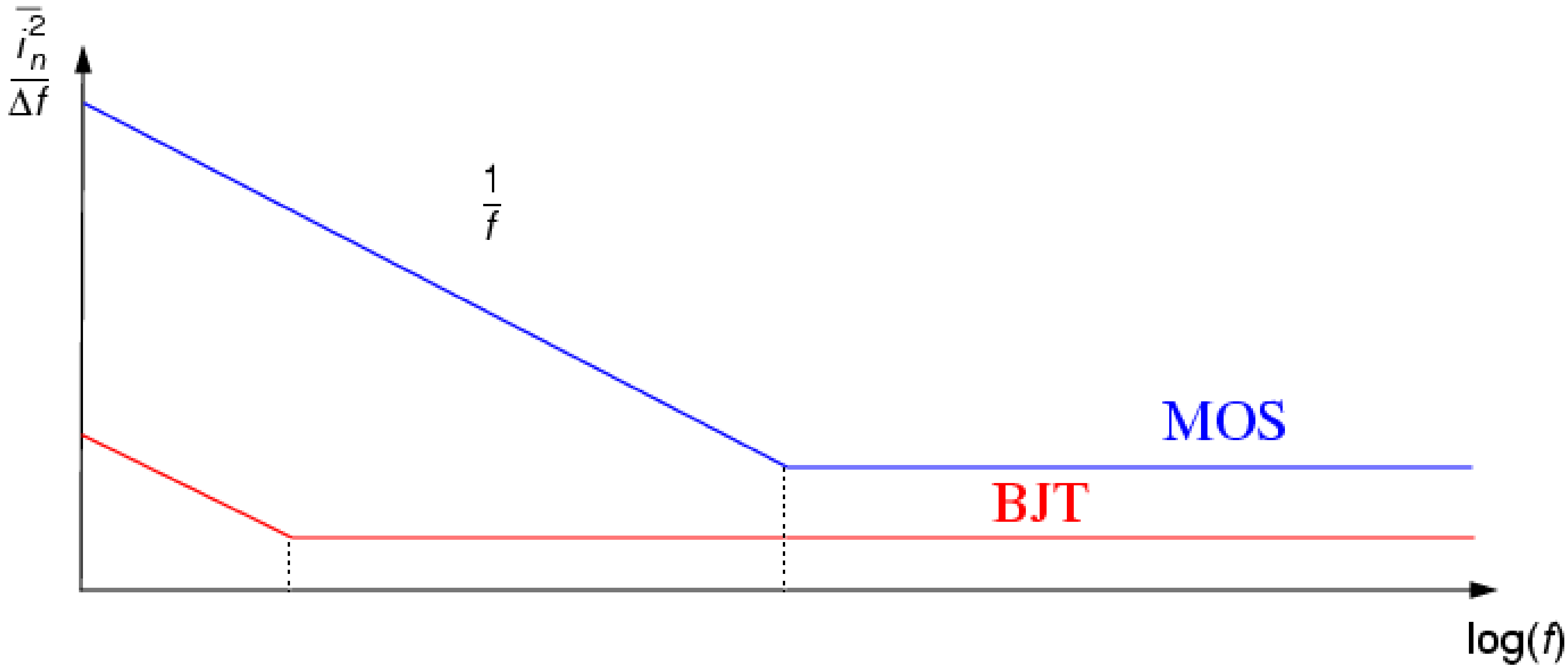




Measured in dB below carrier per unit bandwidth.

$^1/_f$ noise of CMOS vs BJT

Internal noise sources set a fundamental limit for phase noise.



Low frequency noise can be an important contributor to the system noise.

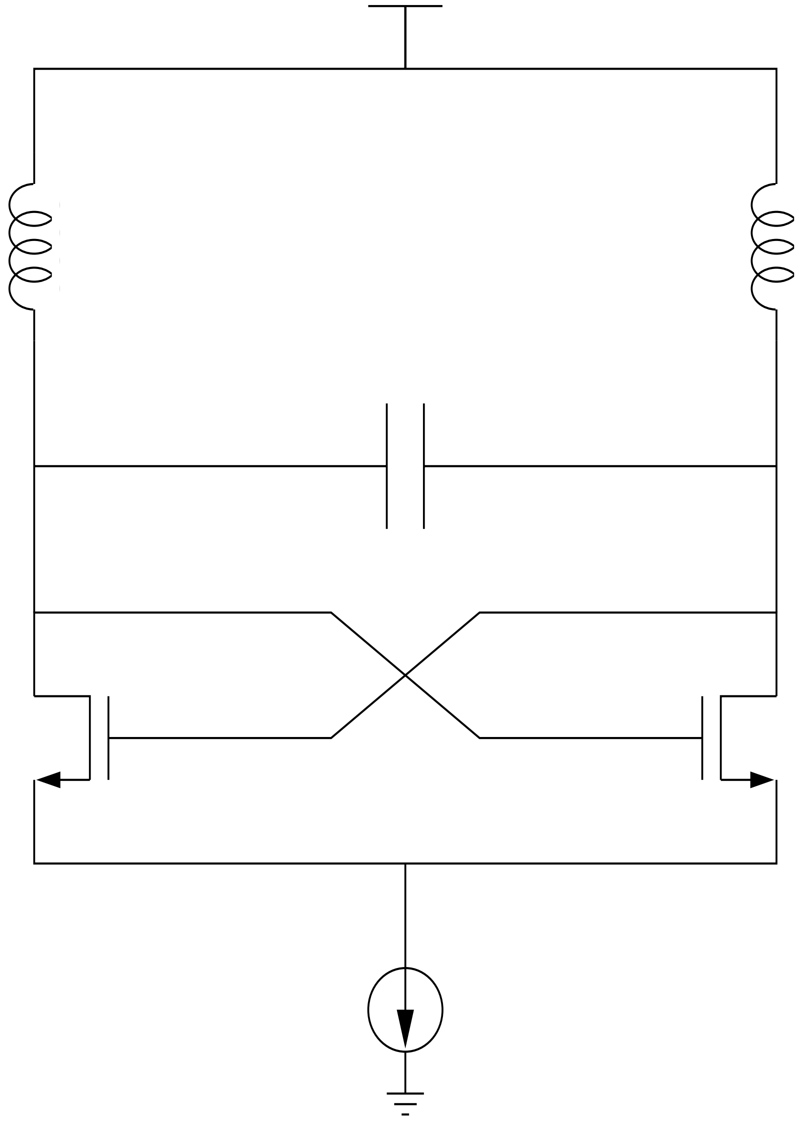
How To Achieve Low Phase Noise

- More Power
- Higher Q Resonant Tank

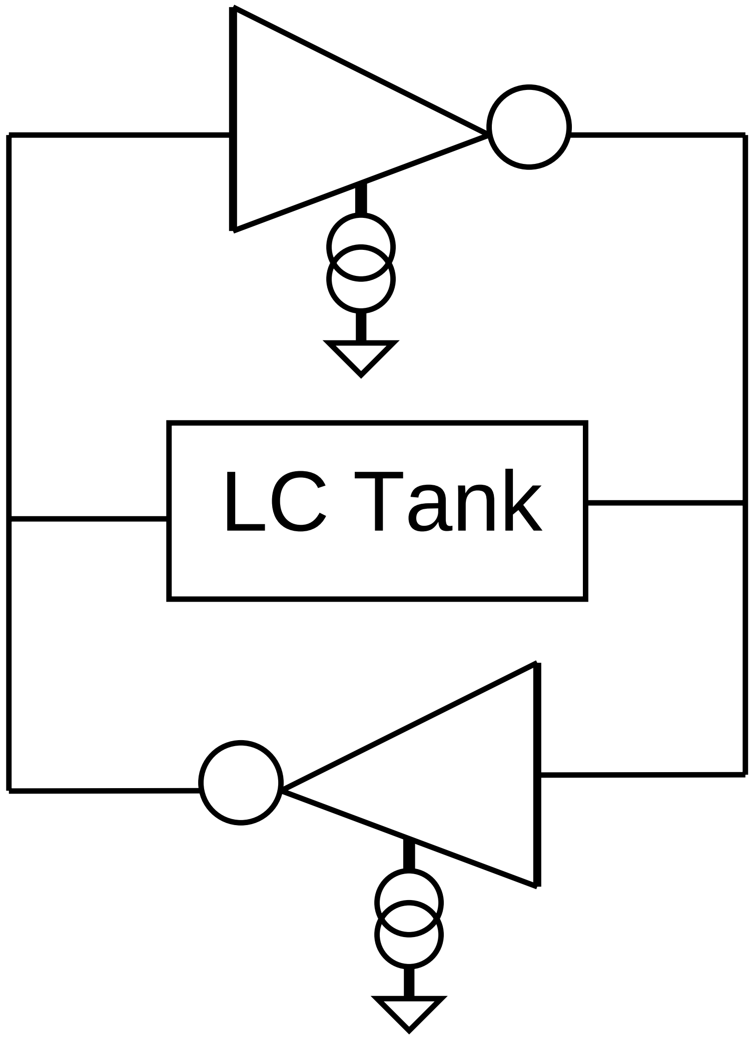
  (use of bond wires and tapping)
- Single-ended Symmetry

  (Hajimiri and Lee, "A general theory of phase noise in electrical oscillators," *IEEE J. Solid-State Circuits*, vol. 33, no. 2, Feb. 1998.)

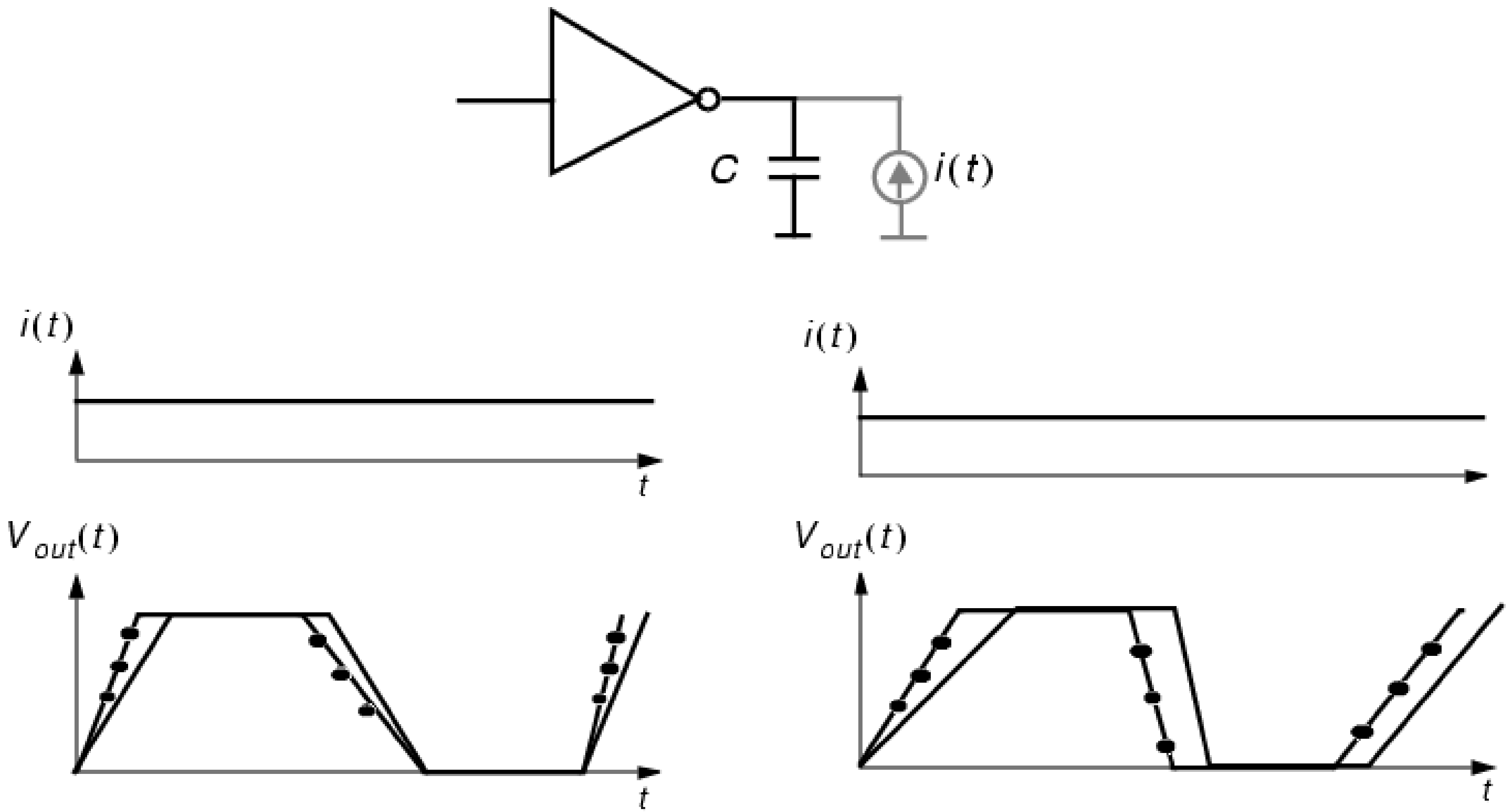
Basic LC Oscillator Configuration



Oscillator Block Diagram



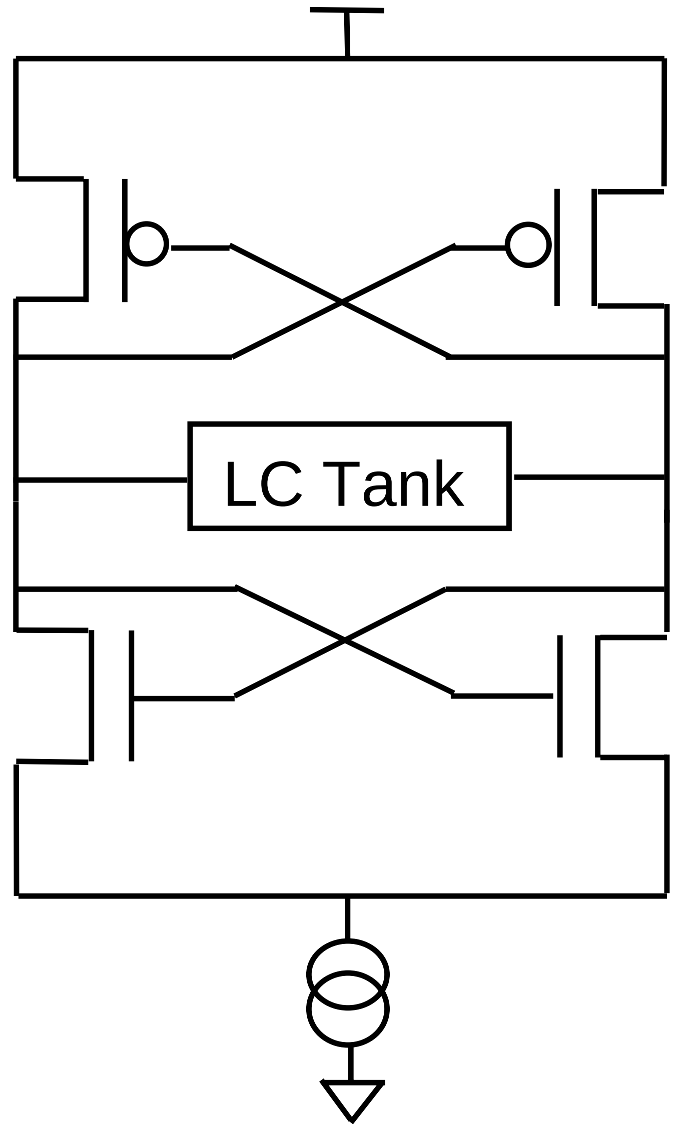
Why Single-sided Symmetry



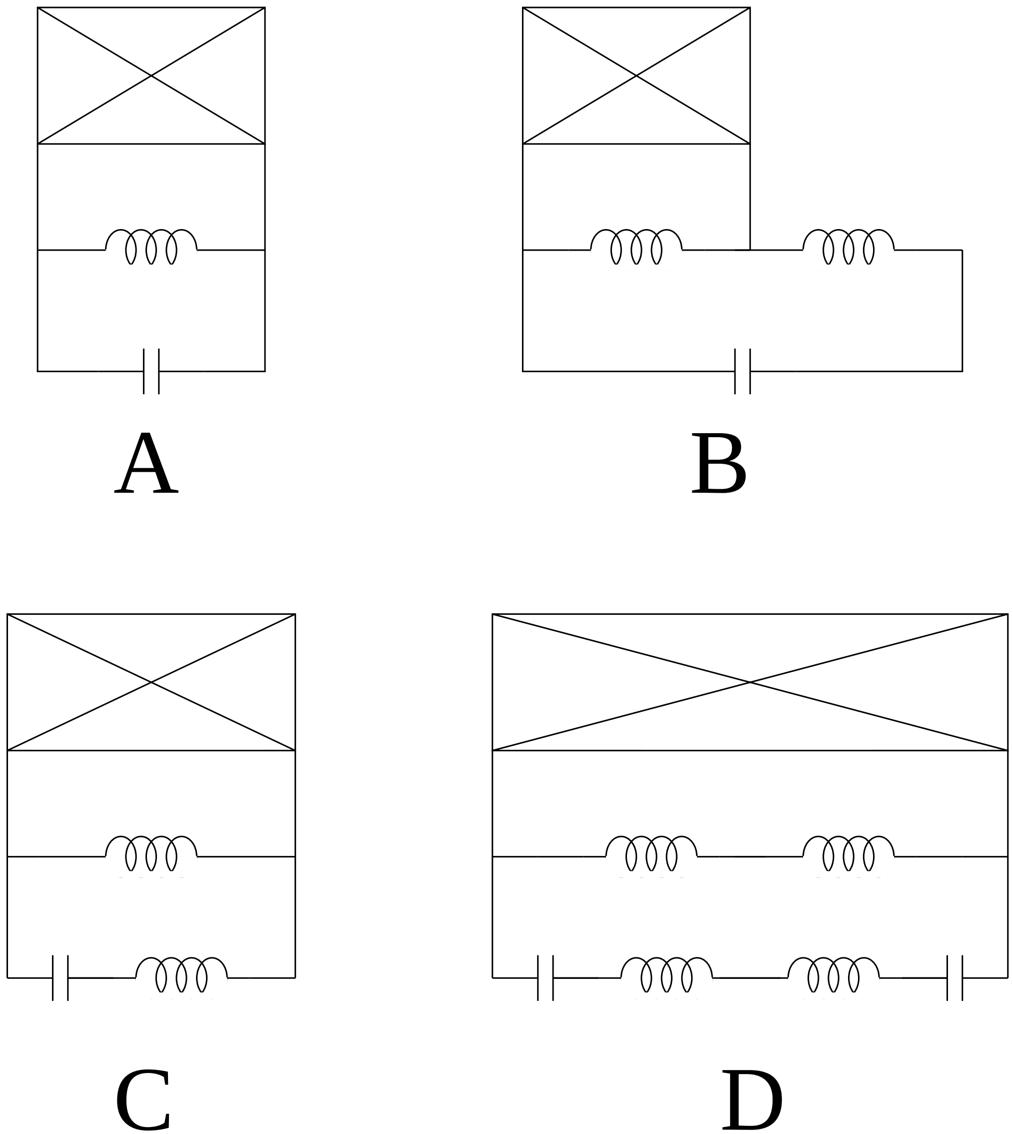
A low frequency current induces a frequency change for the asymmetric waveform.

Basic Design Configuration

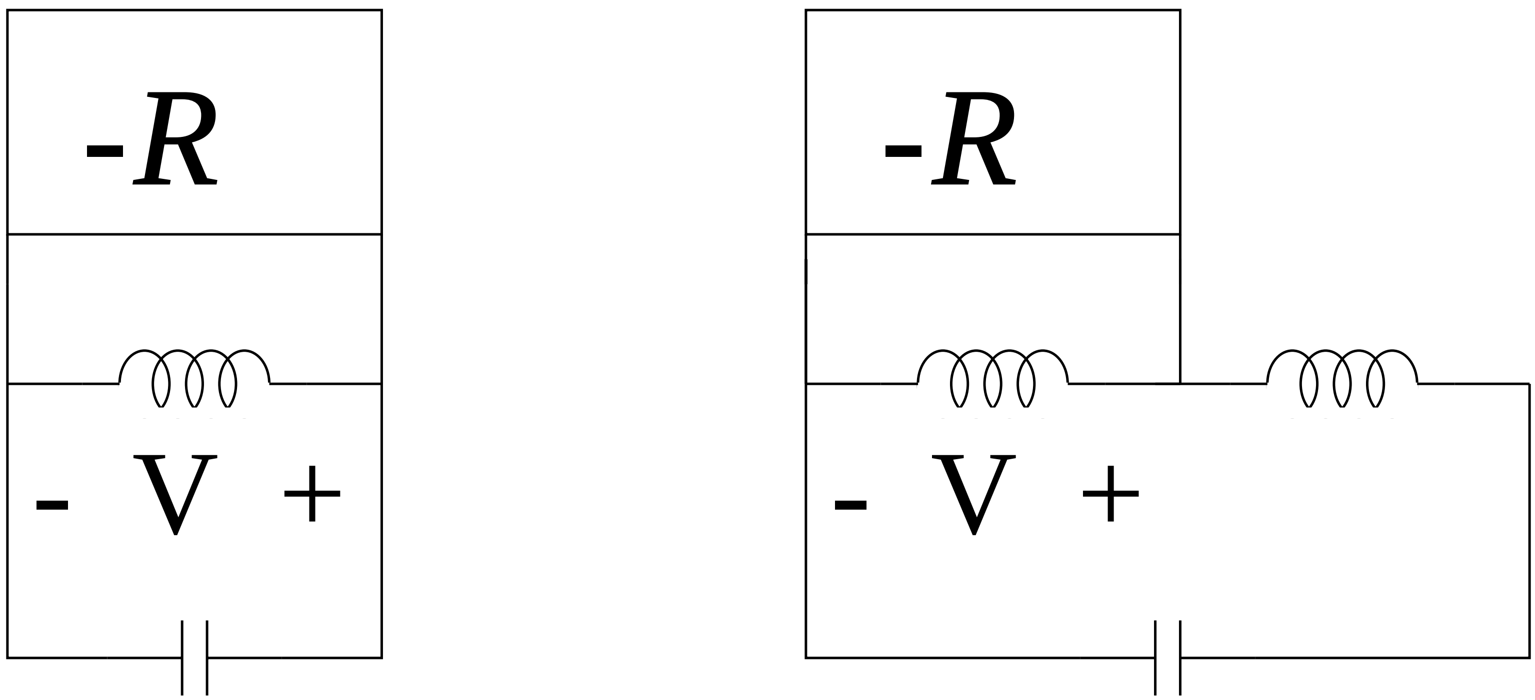
Wp = 2 x Wn



Implementing the LC Tank

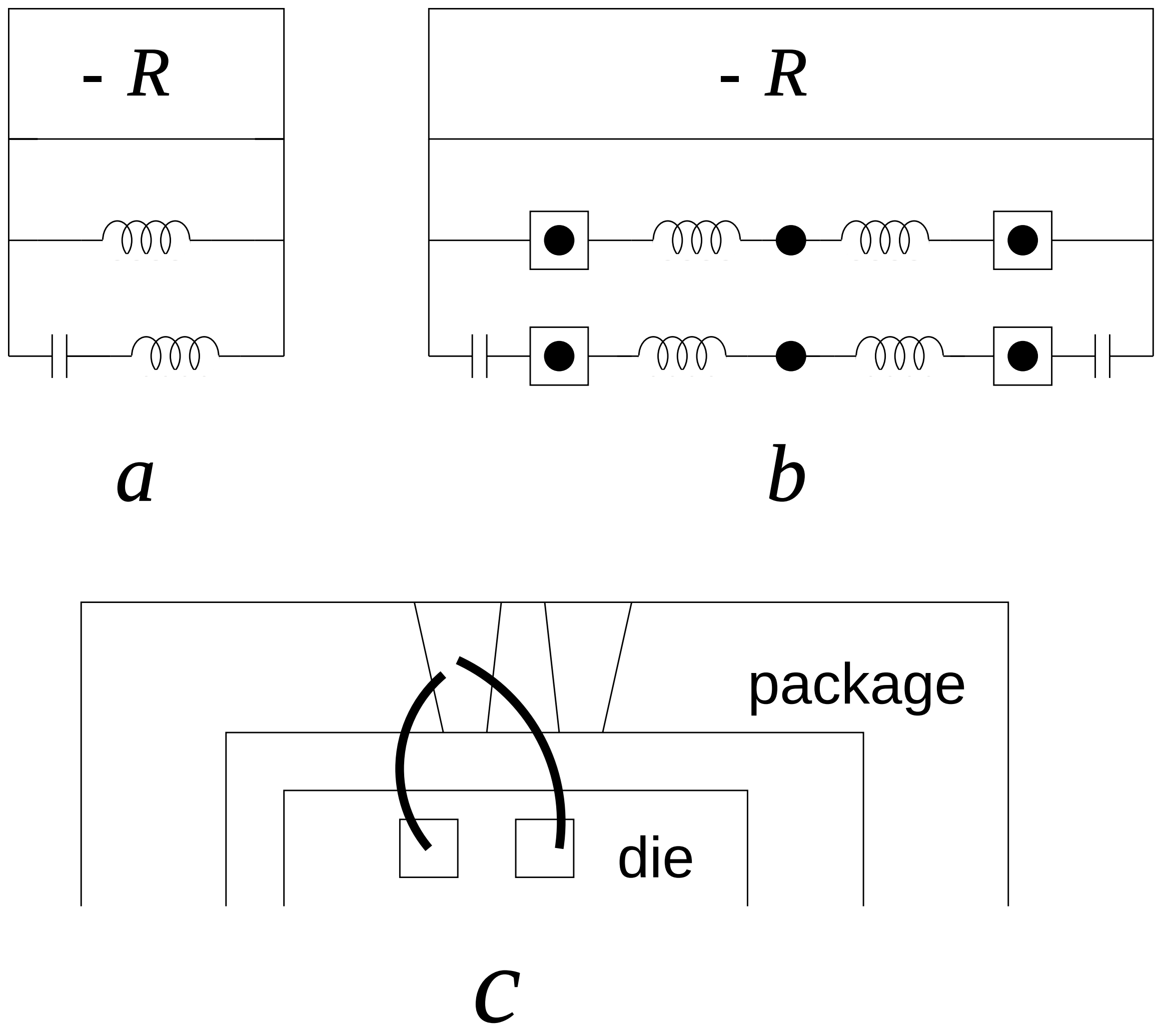


Implementing the LC Tank

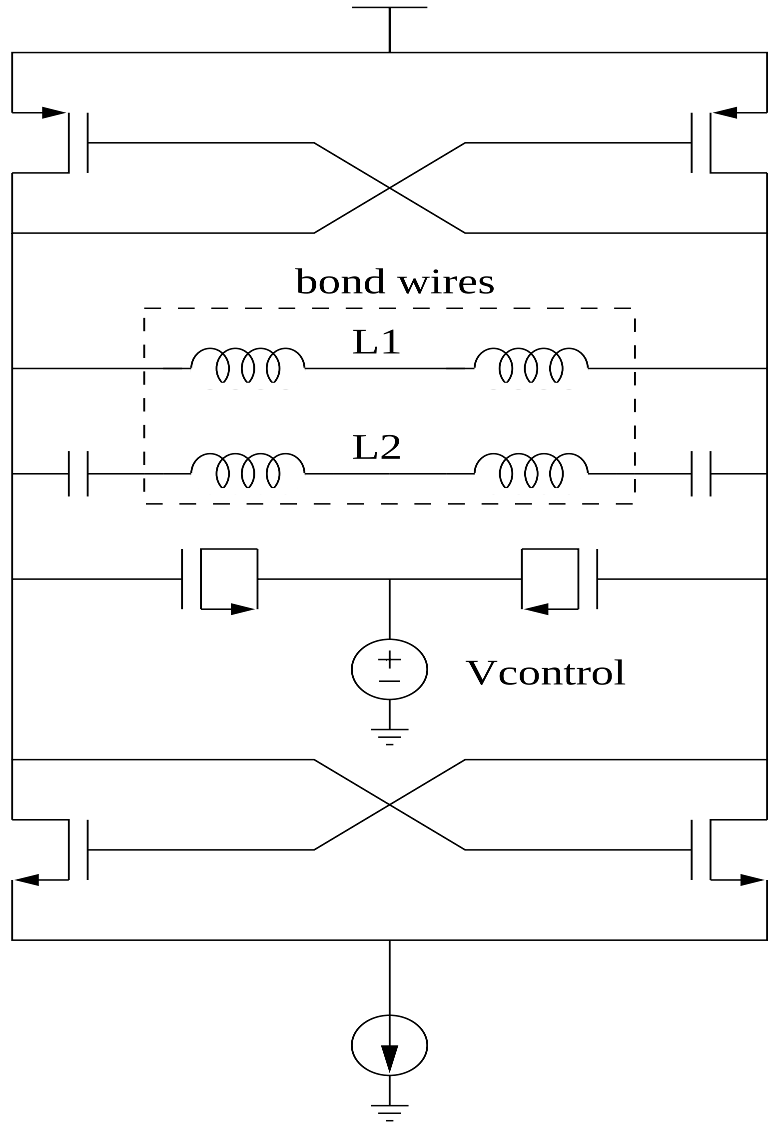


a *b*

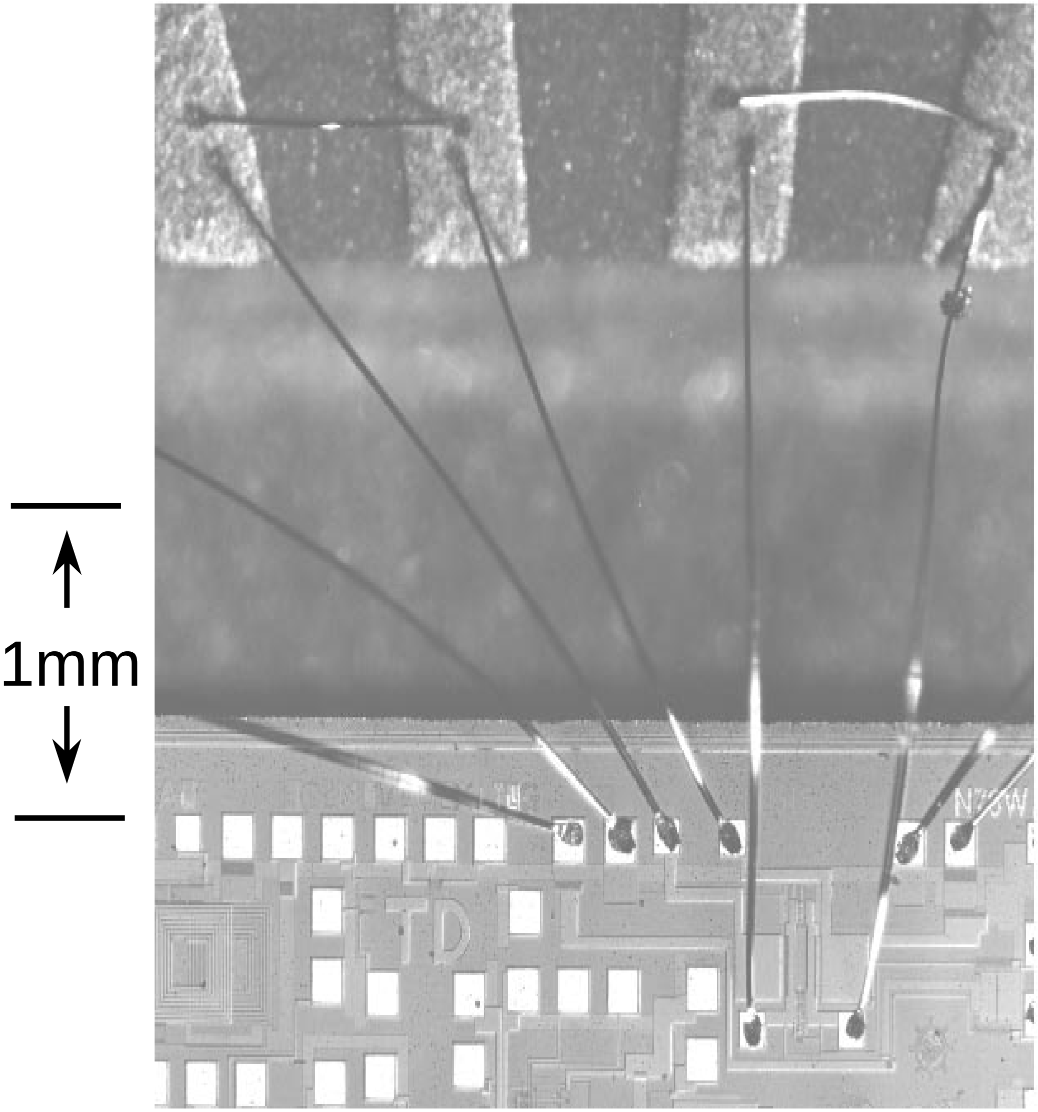
Implementing the LC Tank

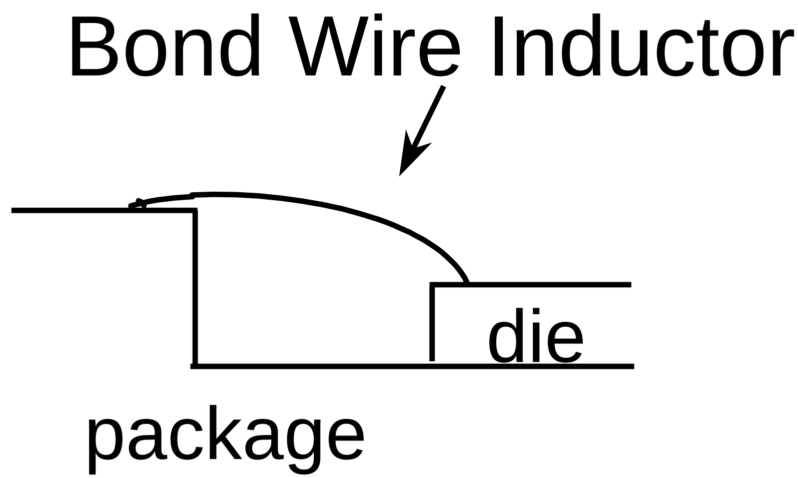


Circuit Diagram

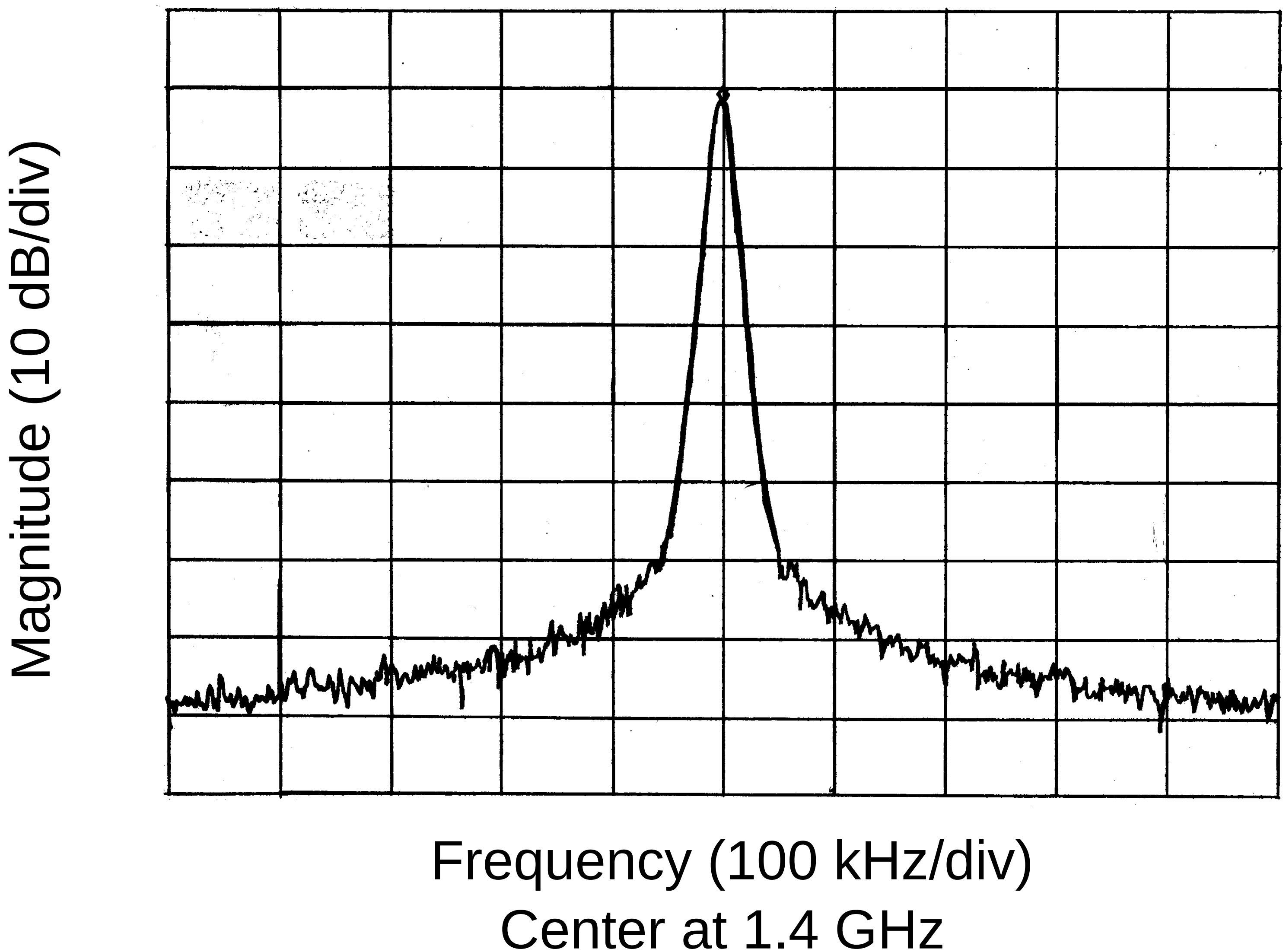


Die Photo and Packaging

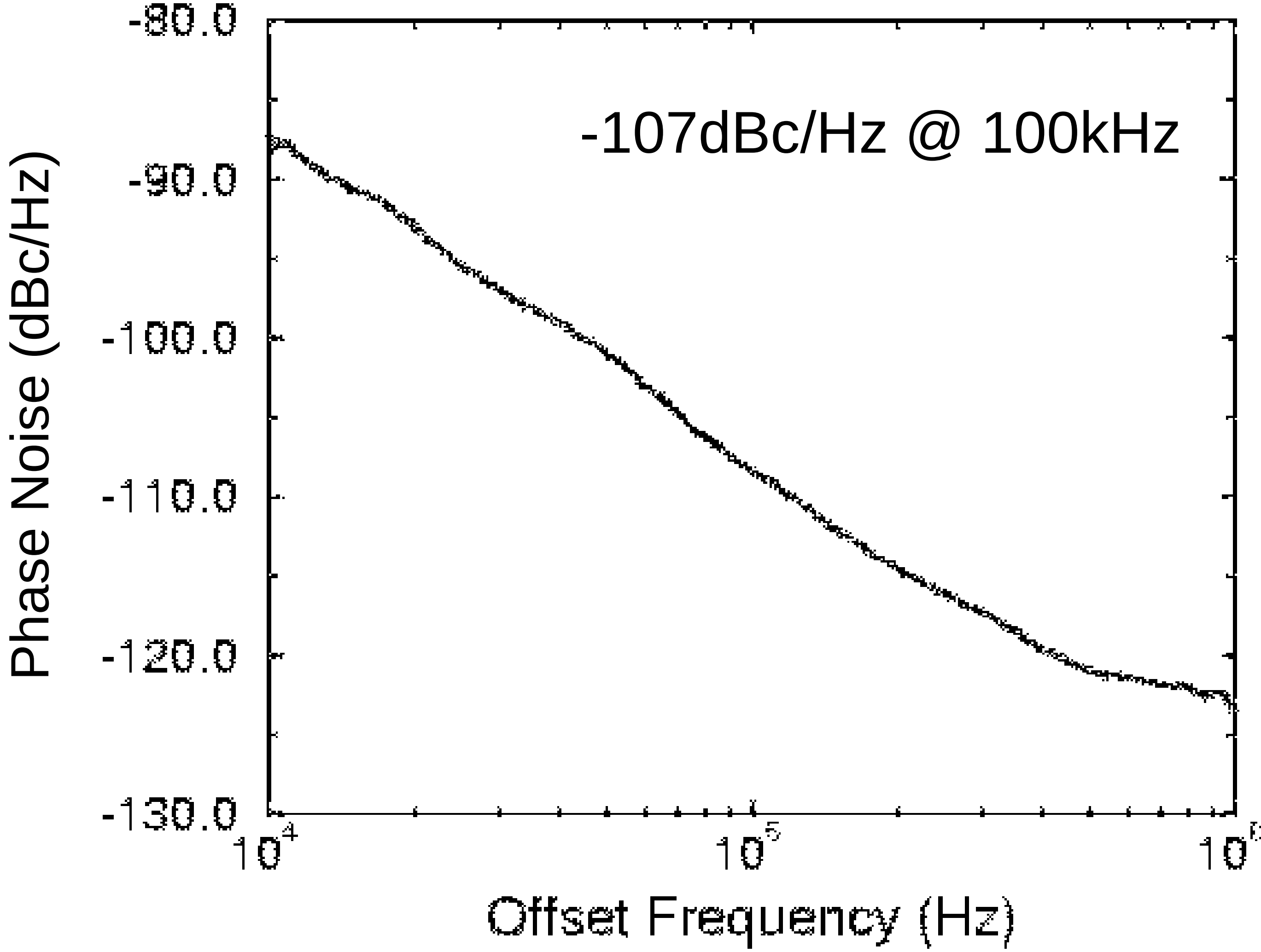




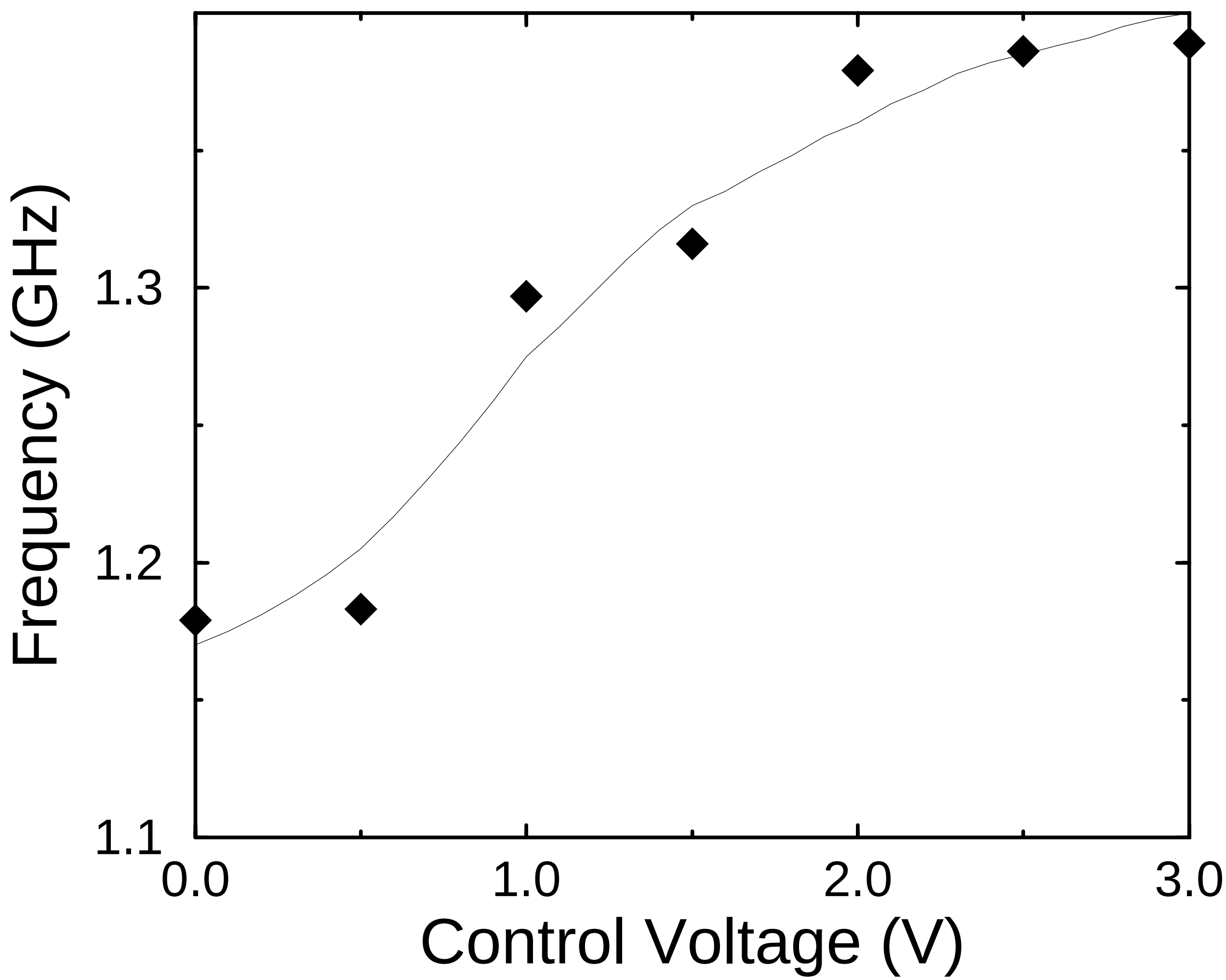
Output Spectrum of Oscillator



Phase Noise vs. Offset Frequency



Frequency vs. Control Voltage



Results

Frequency	1.4 GHz
Power	3 mW at 3.0V supply
Phase Noise for various offsets	-83 dBc/Hz @ 10kHz -107 dBc/Hz @ 100kHz -122 dBc/Hz @ 600kHz
Tuning Range	220 MHz (17%)
Process Technology	0.5-µm standard CMOS

Figure of Merit- CMOS w/Bond Wires

Method	Frequency	Power	Phase Noise (PN) @100kHz	FOM
This work	**1.4 GHz**	**3 mW**	**-107 dBc/Hz**	**315 dBF**
Tapping [3]	**1.8 GHz**	**24 mW**	**-109 dBc/Hz**	**310 dBF**
Single-sided Symmetry [2]	**1.6 GHz**	**0.5 mW**	**-95 dBc/Hz**	**312 dBF**

Figure of Merit(dBF) = 20 log(freq) - PN - 10 log(power)

Figure of Merit- Various Technologies

Technology	Freq	Power	Phase Noise (PN) @100kHz	FOM
This work	**1.4 GHz**	**3 mW**	**-107 dBc/Hz**	**315 dBF**
CMOS [6]	**1.8 GHz**	**6 mW**	**-105 dBc/Hz**	**312 dBF**
BJT [4]	**1.1 GHz**	**2 mW**	**-95 dBc/Hz**	**302 dBF**
BiCMOS [5] BJT oscillator	**1.8 GHz**	**70 mW**	**-88 dBc/Hz**	**285 dBF**

Figure of Merit(dBF) = 20 log(freq) - PN - 10 log(power)

Figure of Merit- Ring vs. LC

Design	Freq	Power	Phase Noise (PN) @100kHz	FOM
This work	**1.4 GHz**	**3 mW**	**-107 dBc/Hz**	**315 dBF**
Ring Oscillator	**1.8 GHz**	**10 mW**	**-75 dBc/Hz**	**280 dBF**
Ring Oscillator	**1.2 GHz**	**20 mW**	**-80 dBc/Hz**	**278 dBF**
Ring Oscillator	**5.4 GHz**	**80 mW**	**-79 dBc/Hz**	**284 dBF**

Figure of Merit(dBF) = 20 log(freq) - PN - 10 log(power)

Conclusions

- Tapping allows a greater amount of energy in the resonant tank, thereby increasing the signal energy without increasing the noise.

- Independently, single-sided symmetry reduces the up-converted low frequency phase noise contribution from the active devices.

- CMOS is a growing and attractive solution for RF oscillators.

Acknowledgements

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