(RTU4A-1)

The Effect of Substrate Noise on VCO Performance

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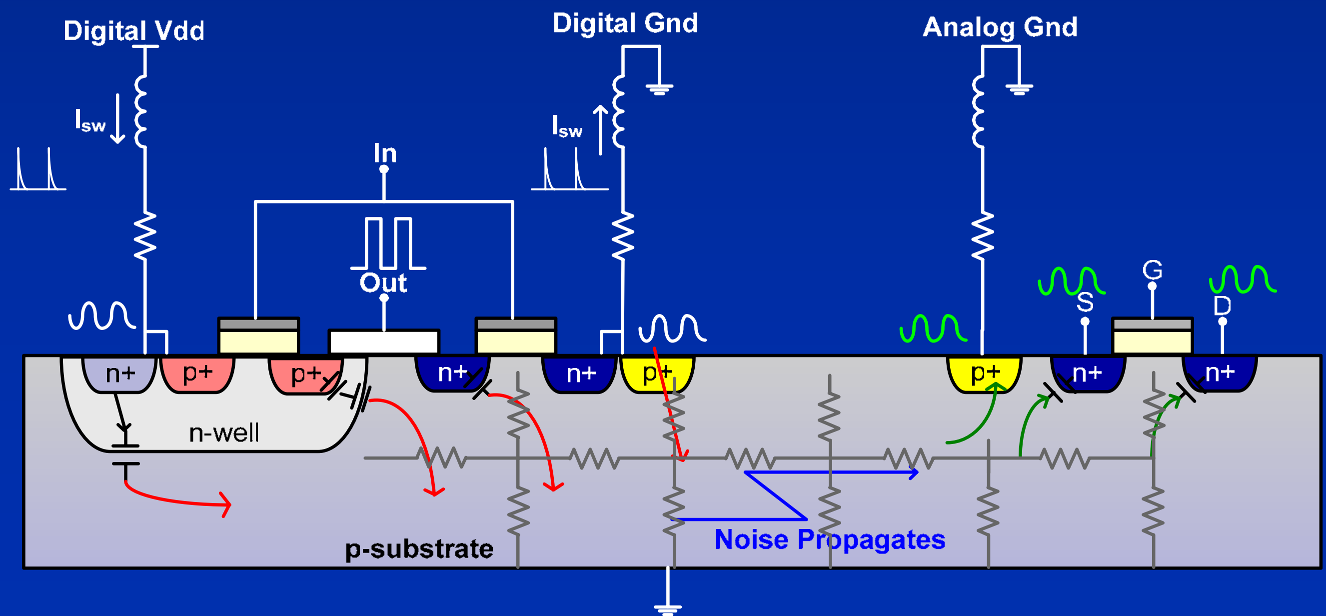
Outline

- Motivation/Background
- Noise Characterization Test Chip
- VCO Results
  - – Effect of Bias Current
  - – Effect of Guard Rings
- Conclusions

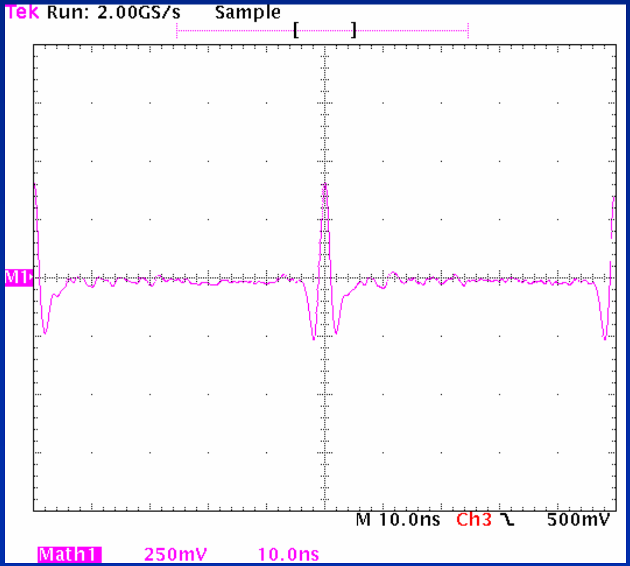
What is Substrate Noise?

- Digital circuits inject noise into substrate during switching
- Noise propagates to analog section via substrate
- Effect on analog circuits: substrate contacts, pickup through large capacitive nodes, backgate effect

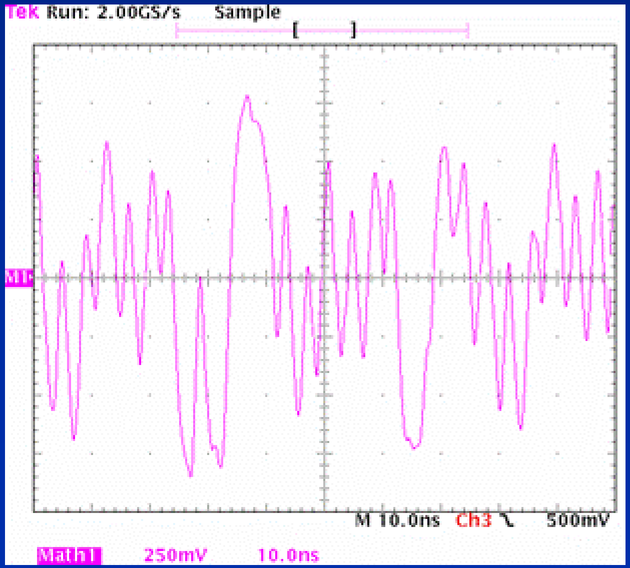


Motivation

- UWB transceiver chip
  - TSMC 0.18 μm mixed mode process



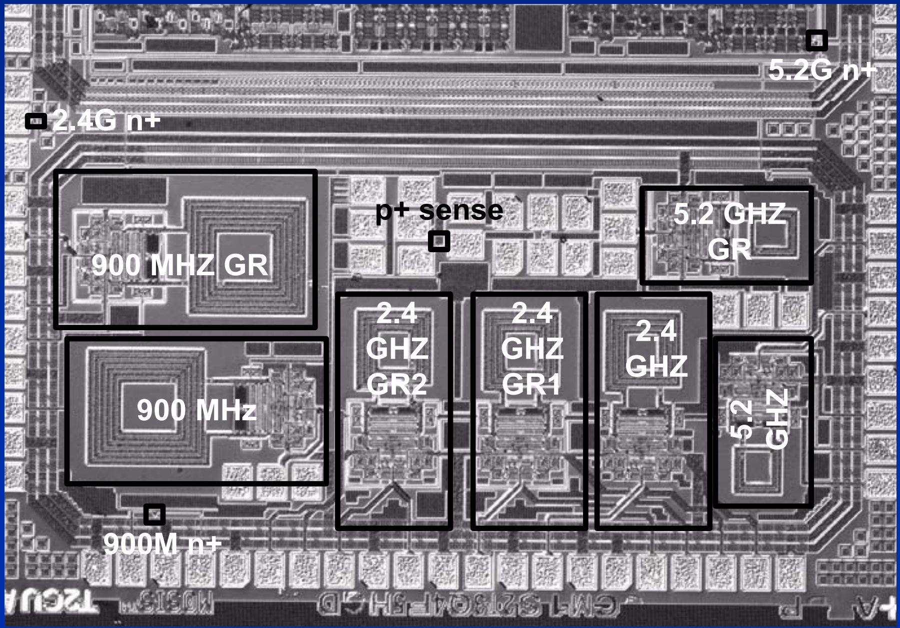
Digital OFF



Digital ON

Noise Characterization Test Chip

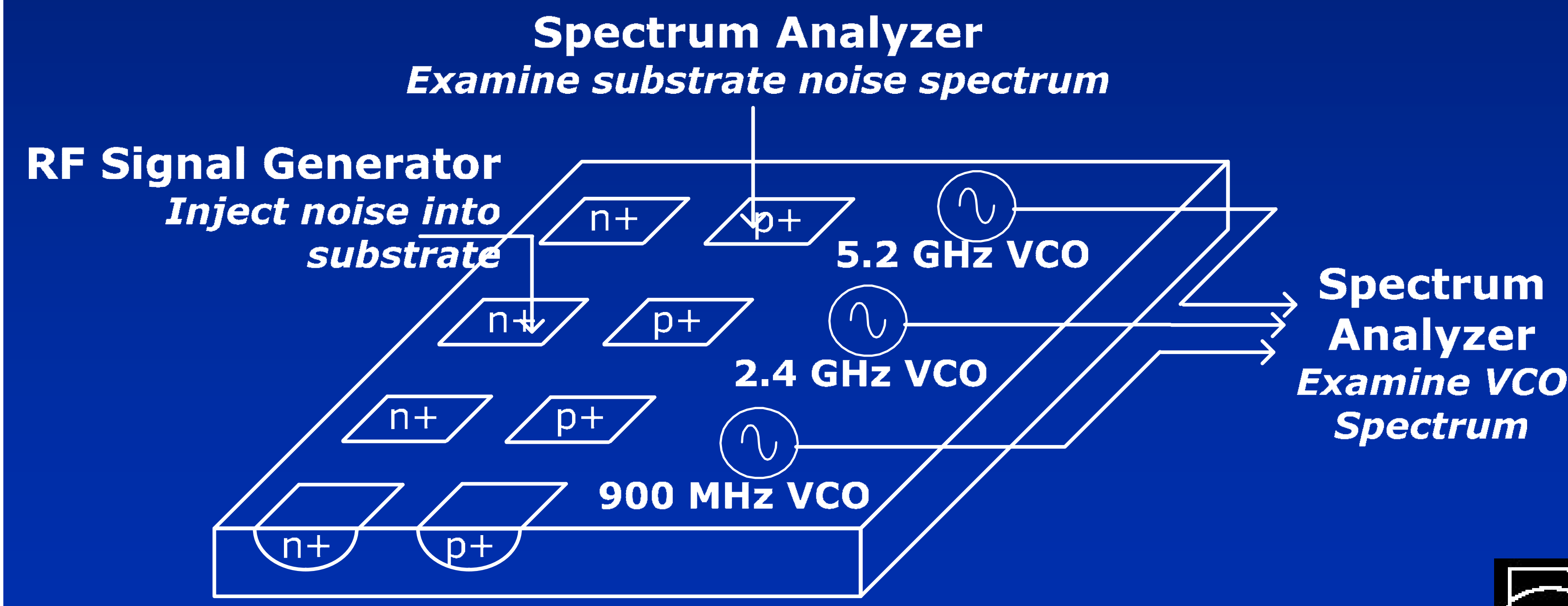
- TSMC 0.18 µm mixed-mode process (non-epi substrate)
- $\rho_{sub} \approx$ 10-15 Ωcm
- Triple-well process (~ 20 dB isolation)



Die Microphotograph of Test Chip

Experimental Setup

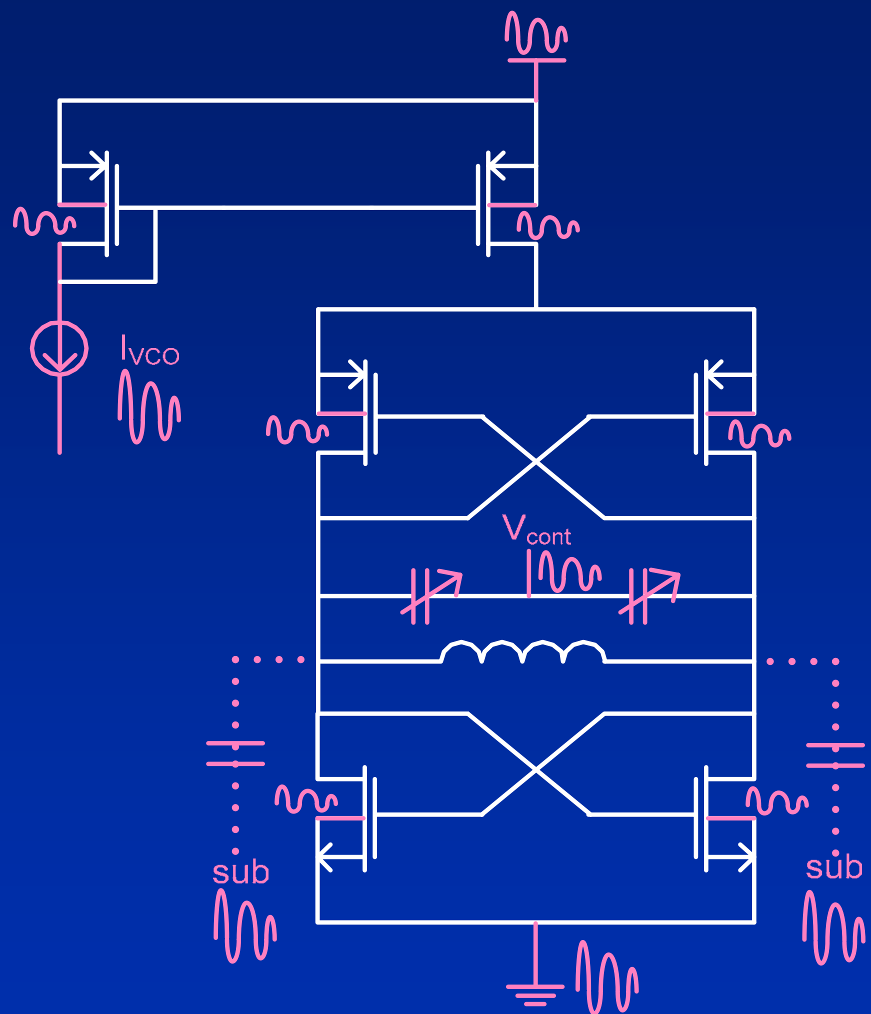
- Multiple injection/sensing locations
- Three VCO center frequencies

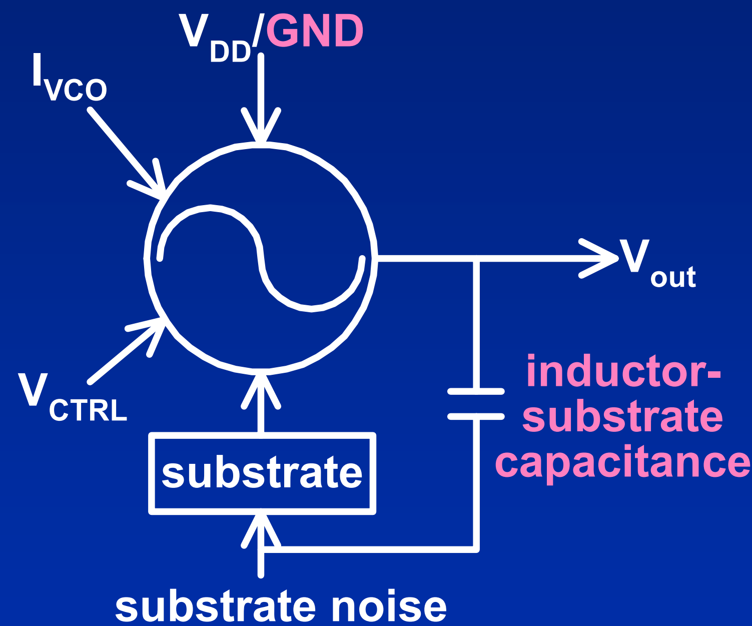


Parameters

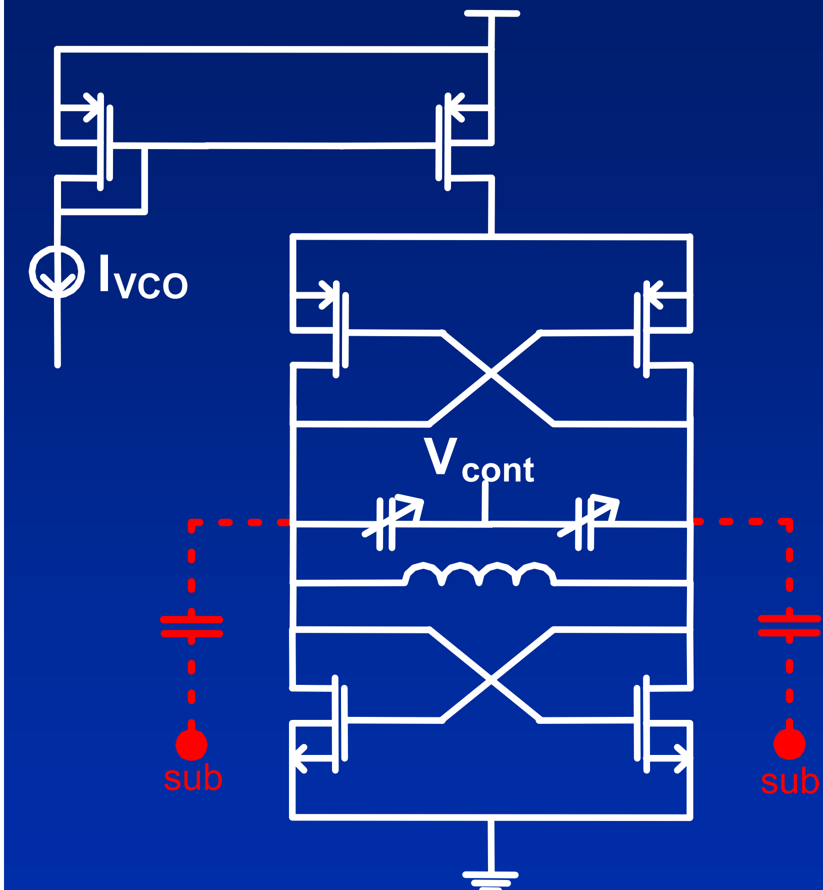
- VCO center frequency
  – 900 MHz, 2.4 GHz, 5.2 GHz
- VCO bias current
- Isolation
  – No guard ring, guard ring

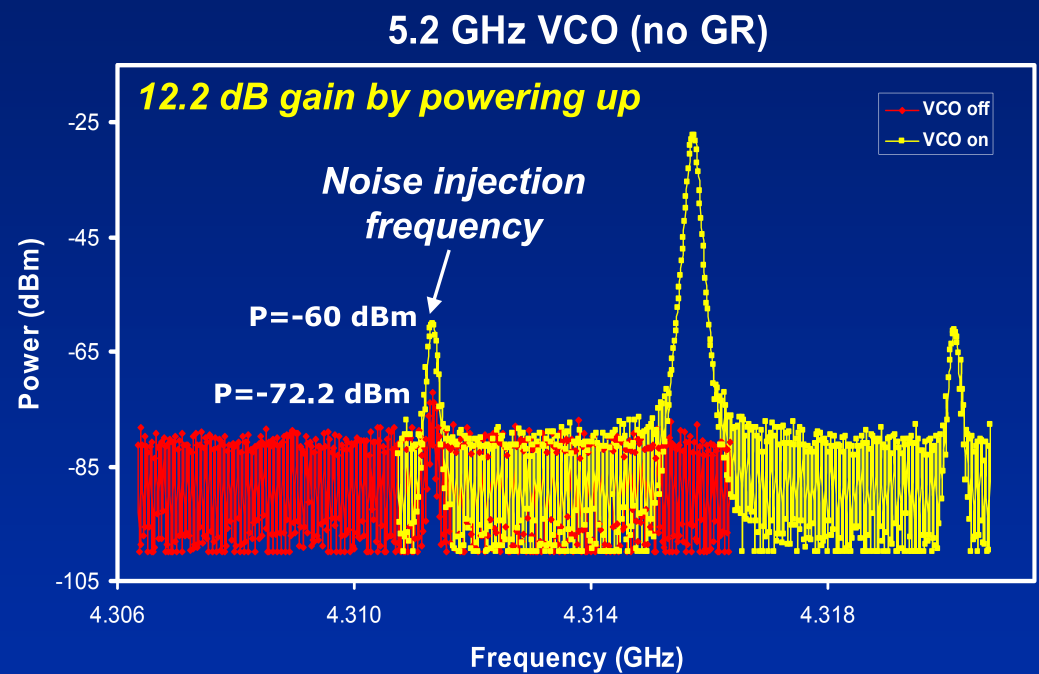
Noise Coupling Paths





Noise Reception

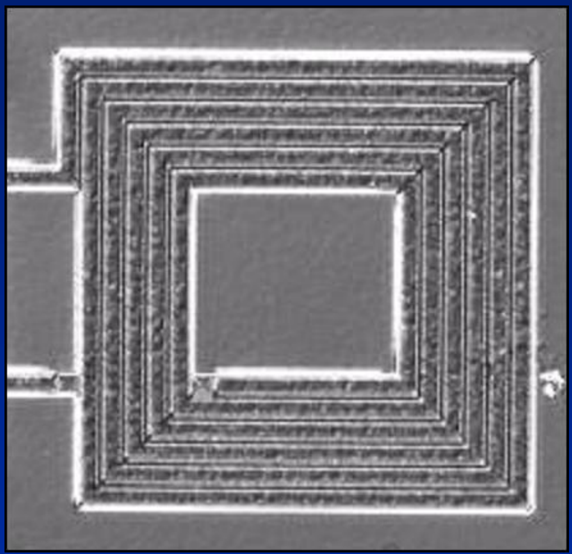




Noise couples through GND line and inductor-substrate capacitance

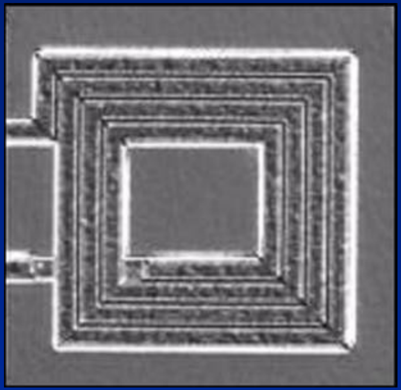
Inductors

900 MHz



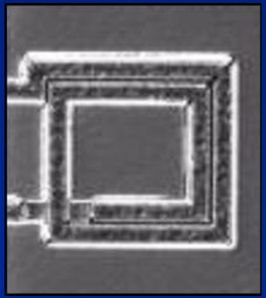
L = 11.4 nH
C = 220 fF
A ≈ 340 x 340 μm^2

2.4 GHz



L = 3.19 nH
C = 100 fF
A ≈ 220 x 220 μm^2

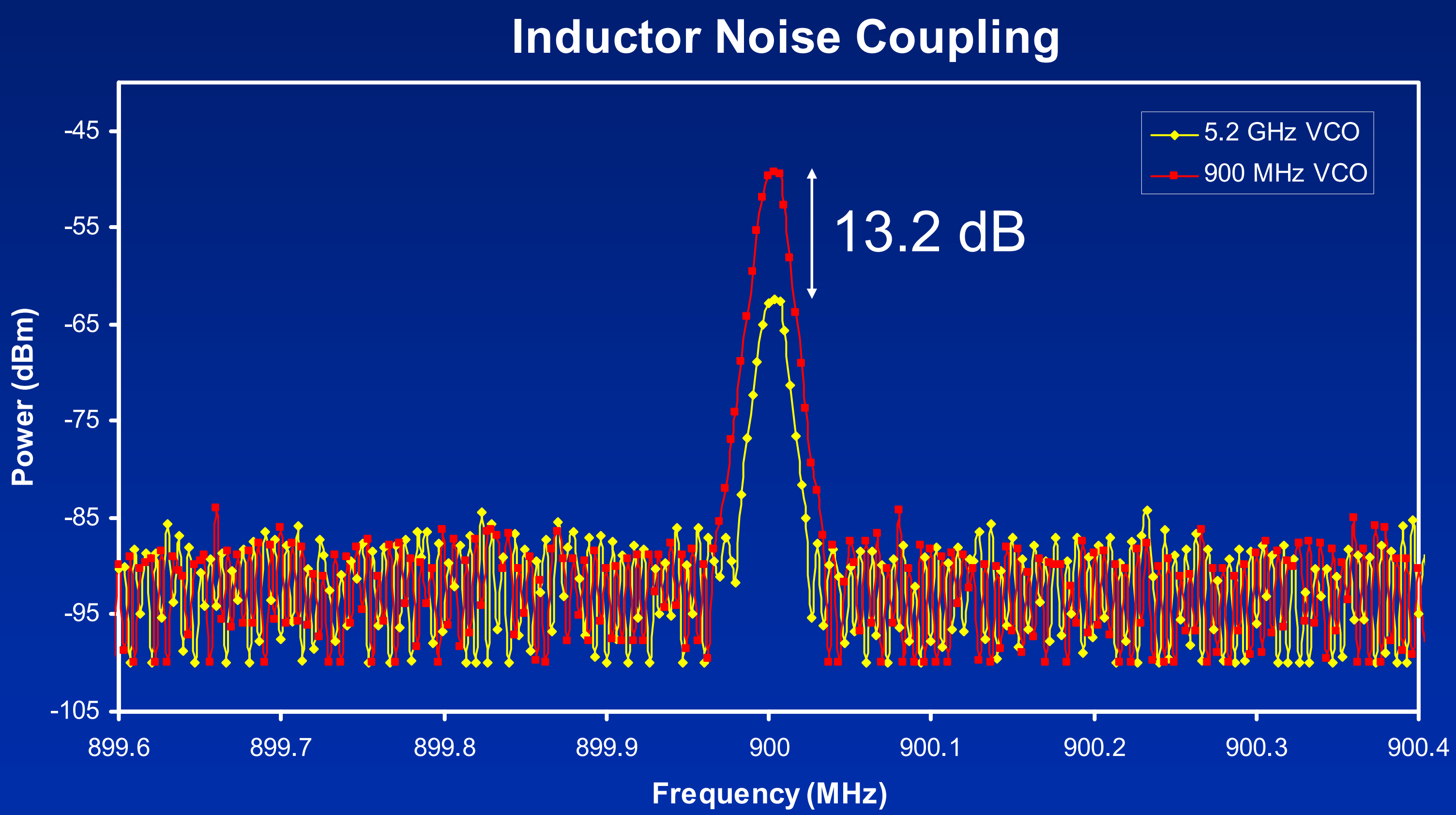
5.2 GHz



L = 655 pH
C = 38 fF
A ≈ 140 x 140 μm^2

Noise coupling through inductor decreases

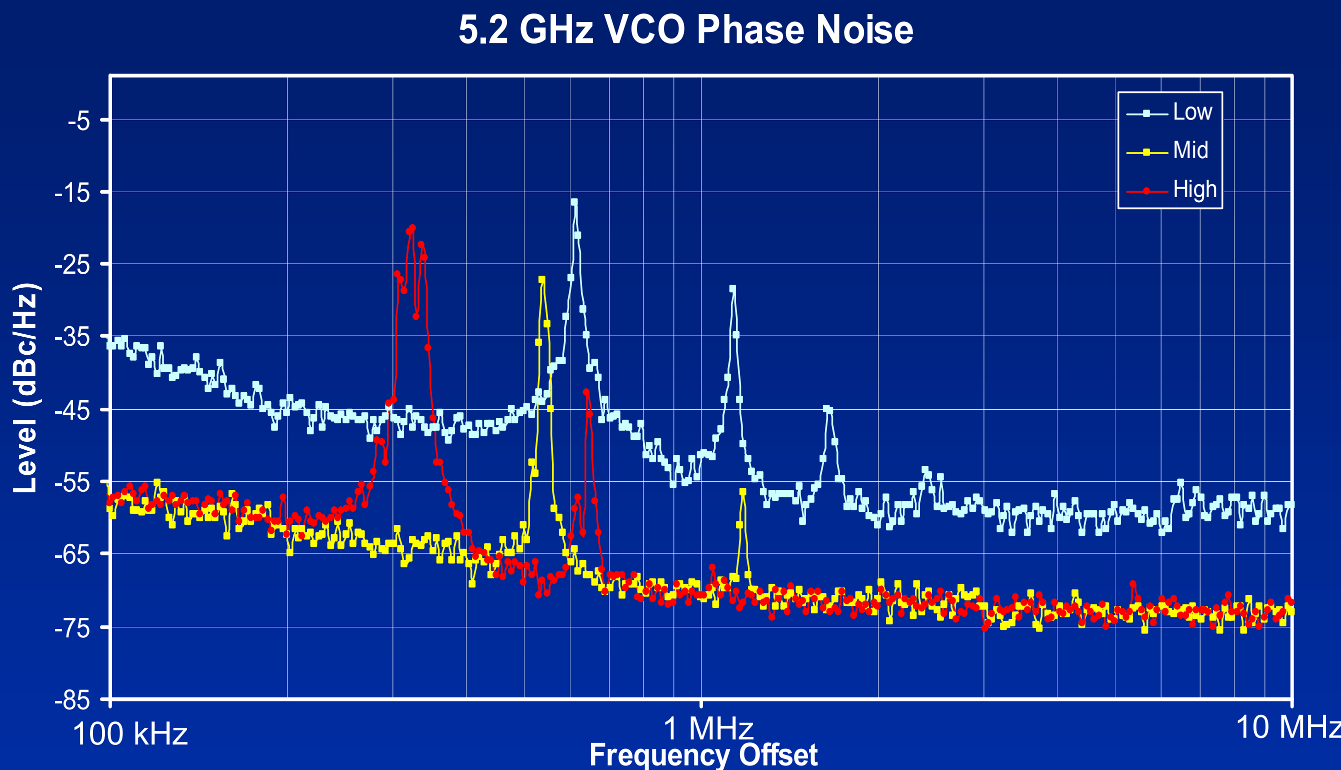
Noise -- Inductor Component



Parameters

- VCO center frequency
  - 900 MHz, 2.4 GHz, 5.2 GHz
- *VCO bias current*
- Isolation
  - No guard ring, guard ring

Effect of VCO Bias Current



I_{LOW} = 1.81 mA
I_{MID} = 2.71 mA
I_{HIGH} = 3.41 mA

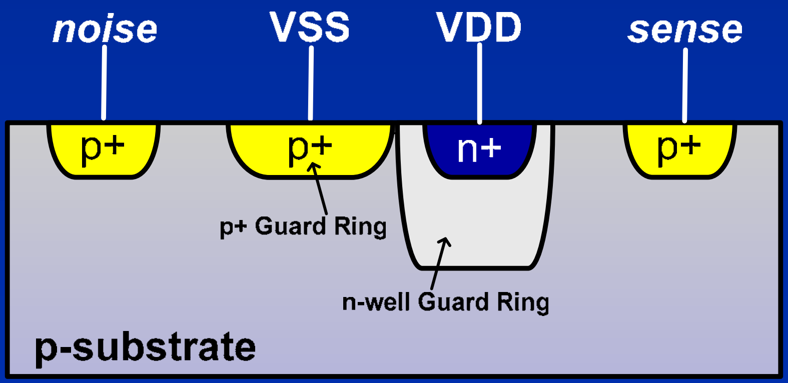
I_{BUFF} = 2.73 mA

I_{VCO}	P_c/P_n (dB)
1.81 mA	9.9 dB
2.71 mA	26.3 dB
3.41 mA	23.1 dB

Ratio of carrier to noise power for 5.2 GHz VCO

Parameters

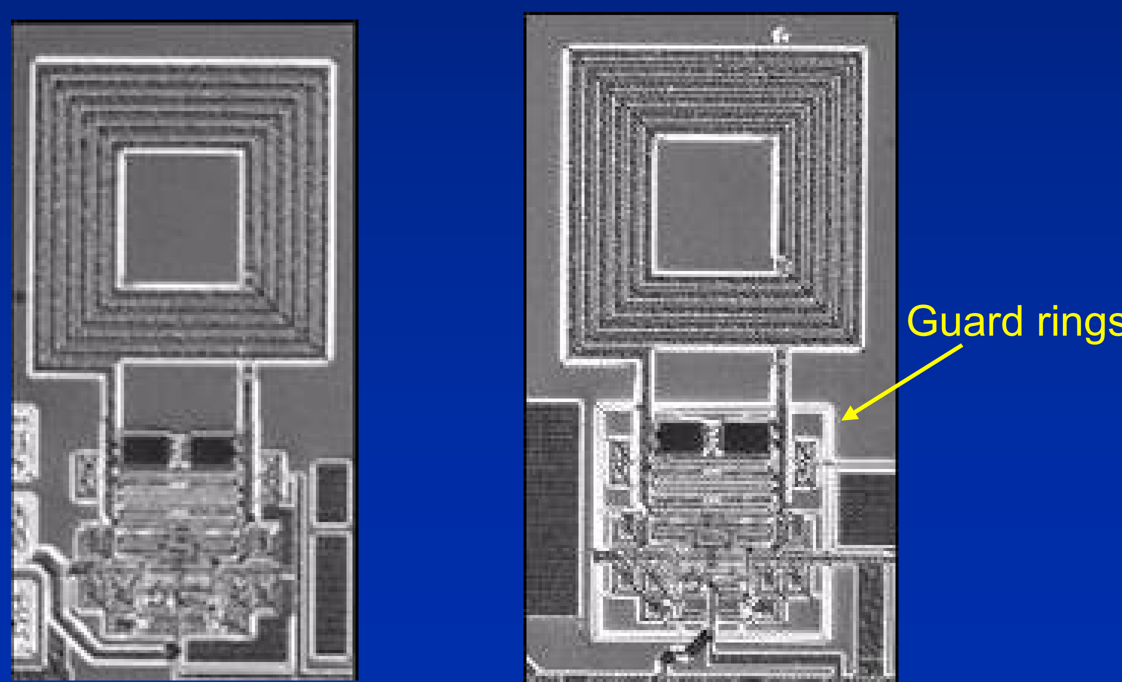
- VCO center frequency
  - 900 MHz, 2.4 GHz, 5.2 GHz
- VCO bias current
- *Isolation*
  - *No guard ring, guard ring*



Dual guard rings

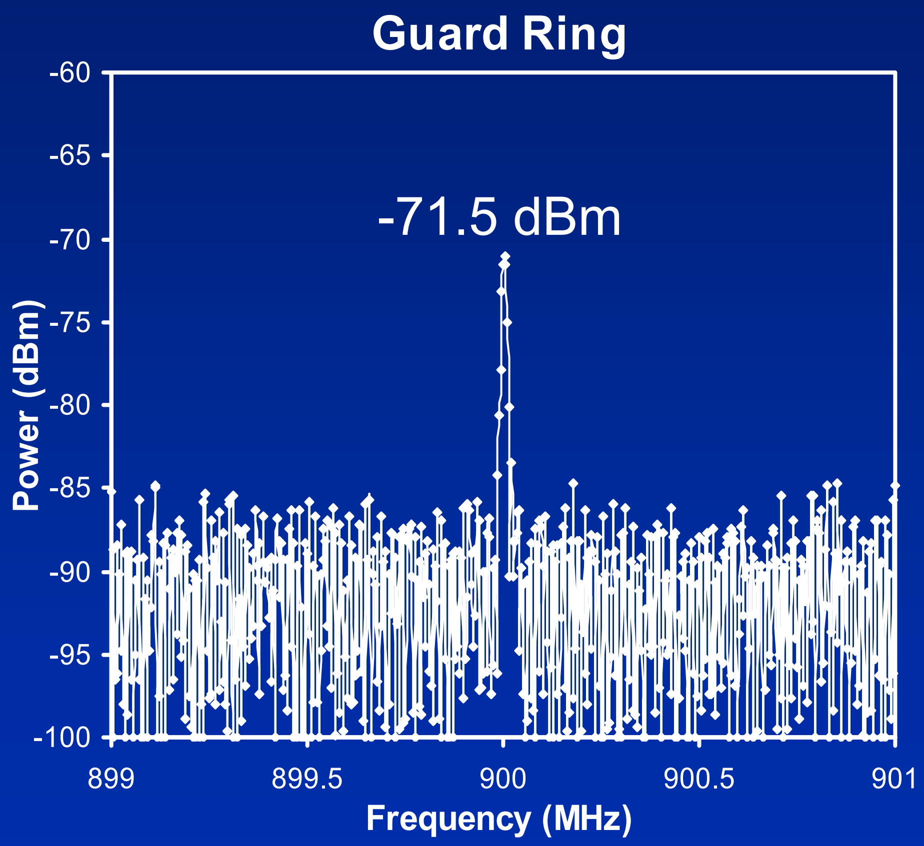
Effect of Guard Rings

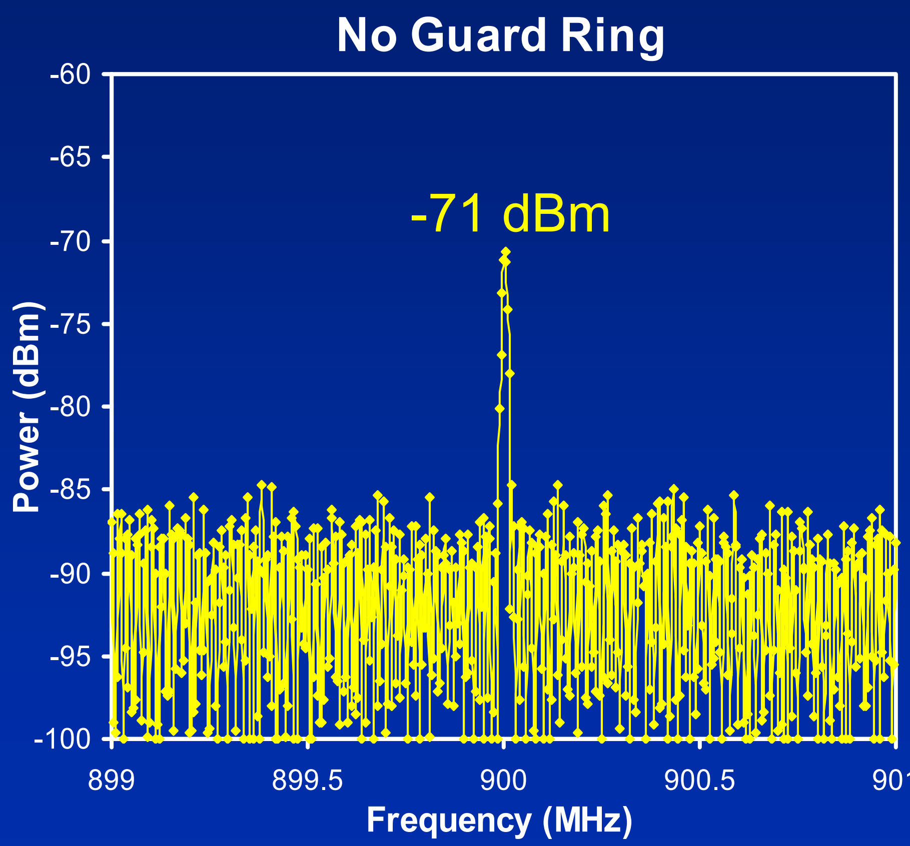
- Guard rings only surround active devices
  - Can only attenuate ground component of noise



Guard Rings and Inductor-Sub Noise

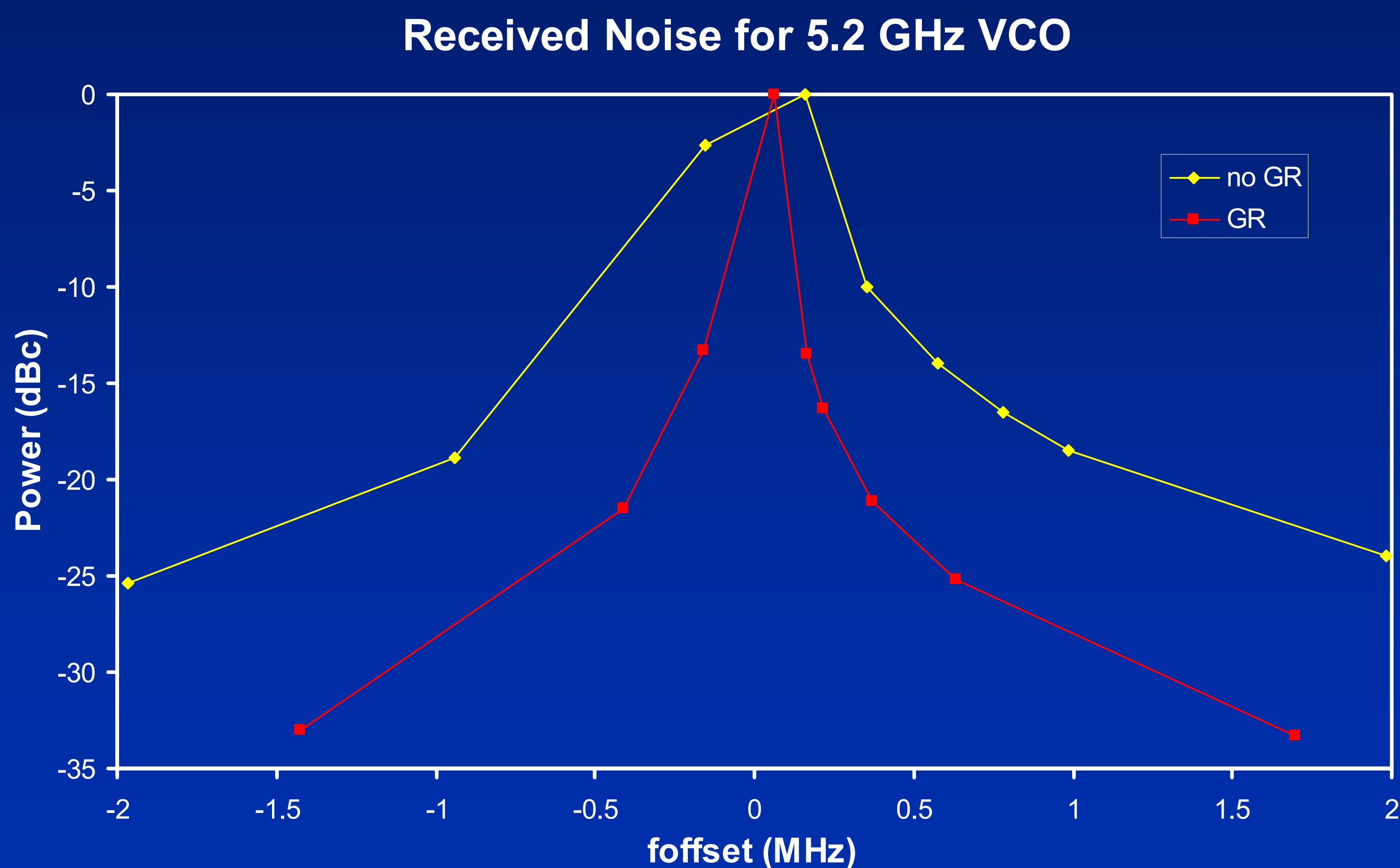
- Guard ring has no effect on inductor component





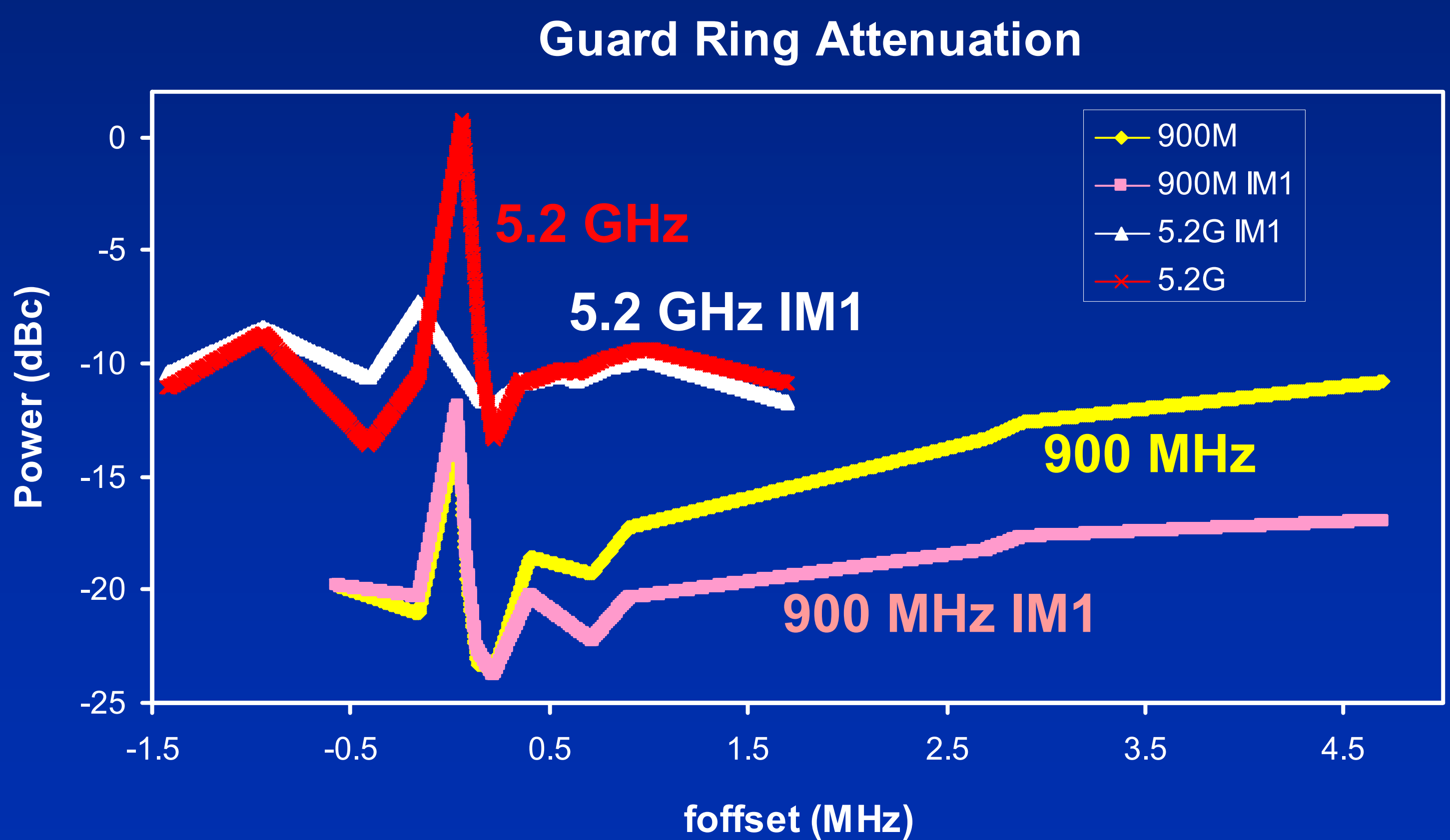
Test: VCO powered off. Noise injected at 900 MHz

Effect of Guard Ring for 5.2 GHz VCO



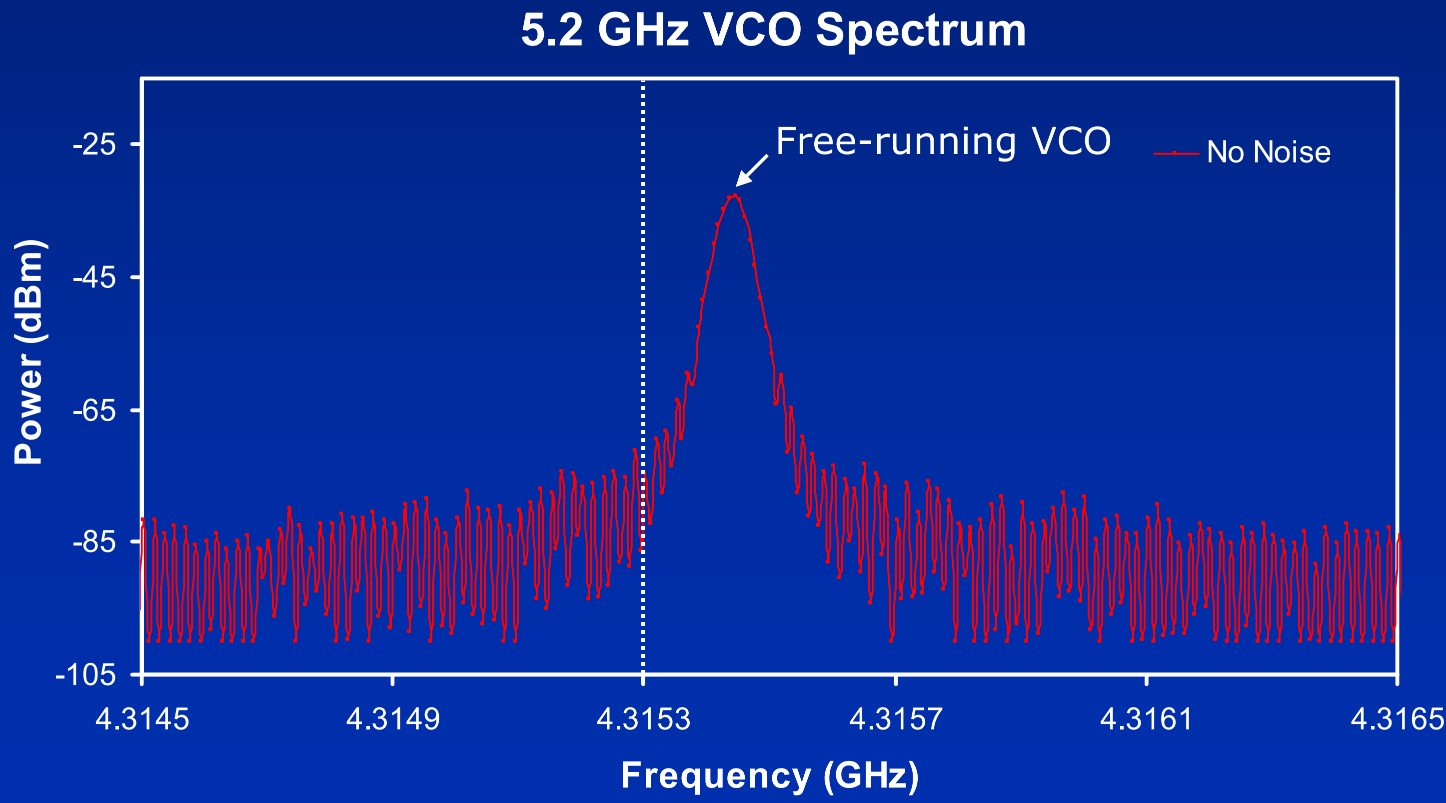
Guard Ring Attenuation

- 900 MHz: -23.4 dB to -13.1 dB
- 5.2 GHz: -13.5 dB to 0.64 dB



VCO Locking

- As f_{noise} approaches f_{VCO}, and if P_{noise} is comparable to $P_{carrier}$, VCO can lock to f_{noise}



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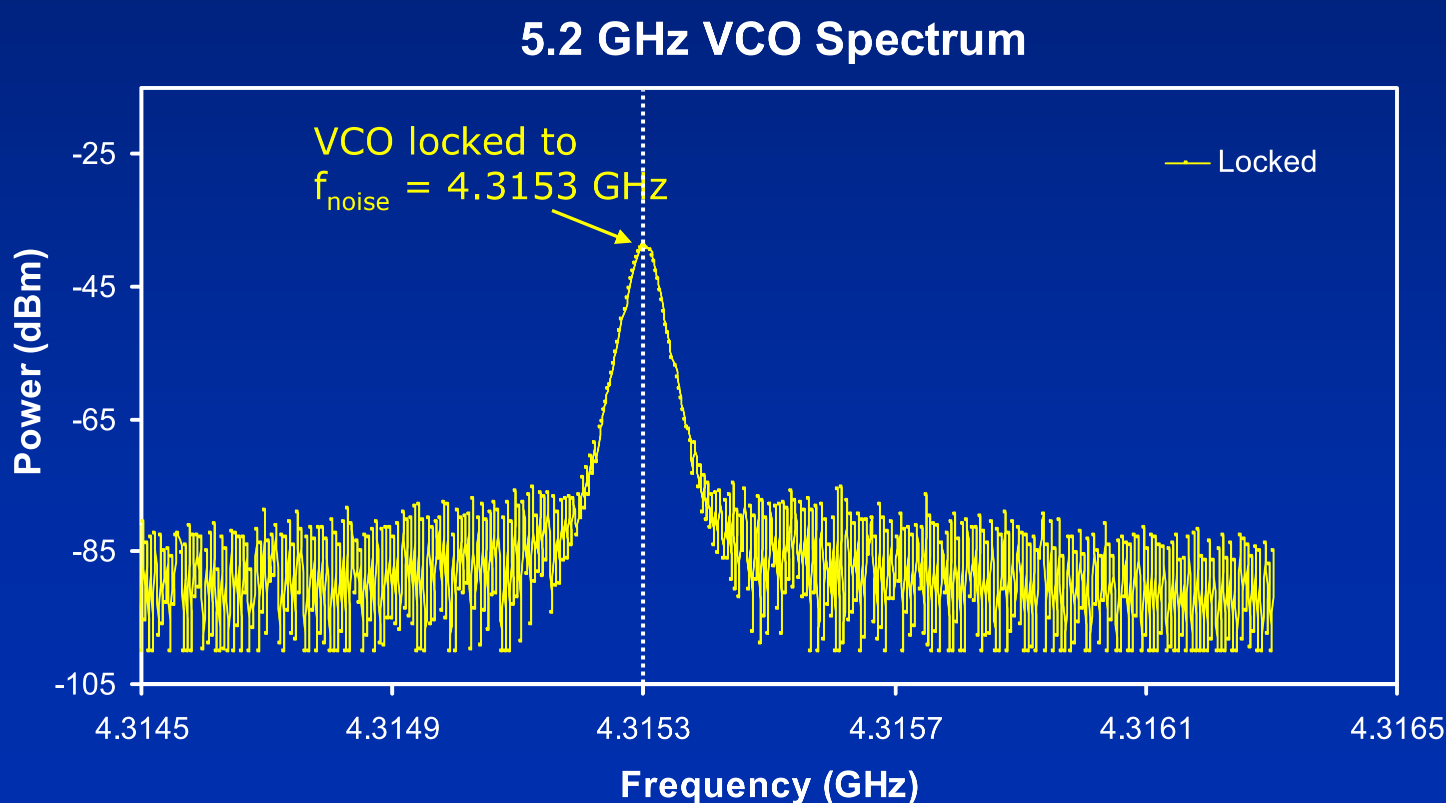

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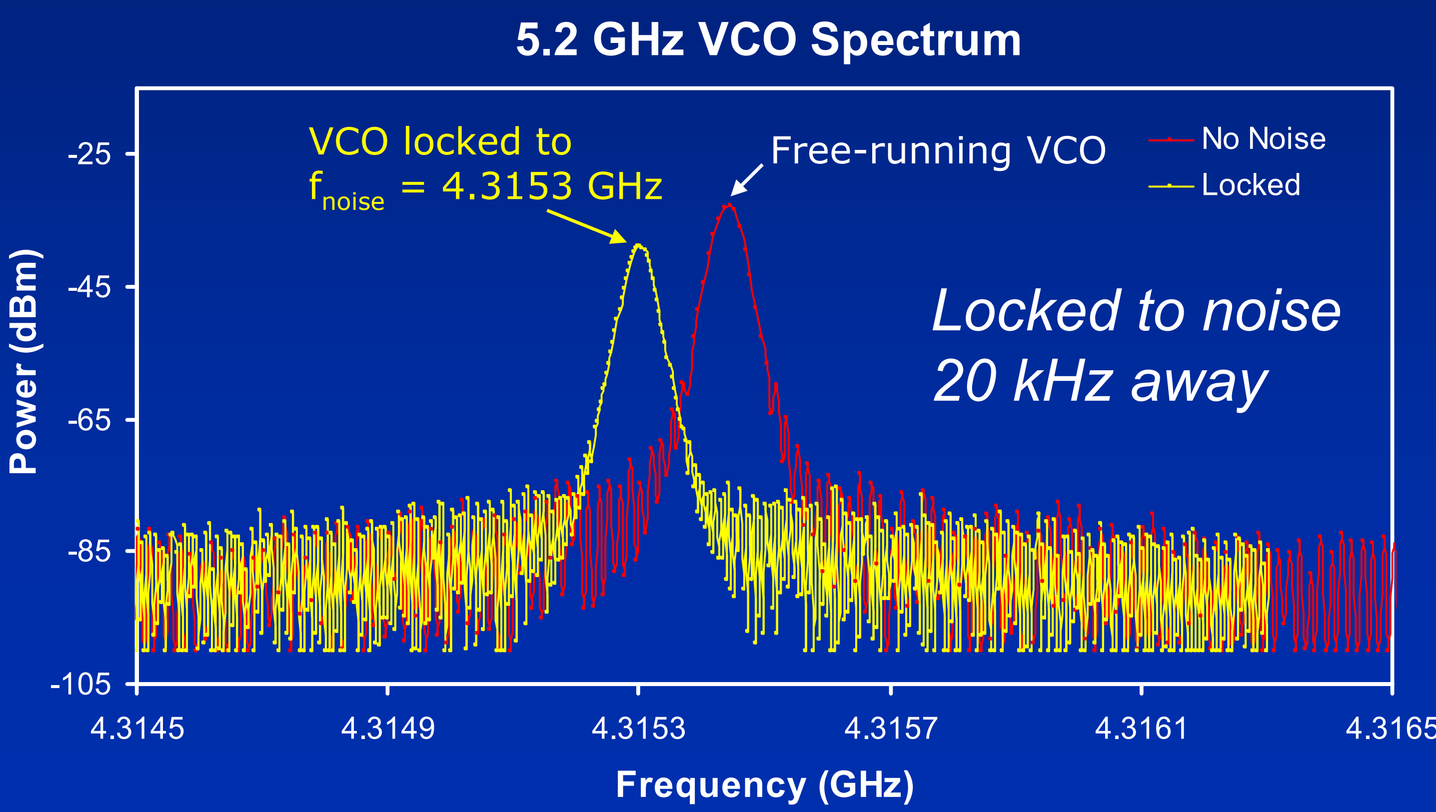
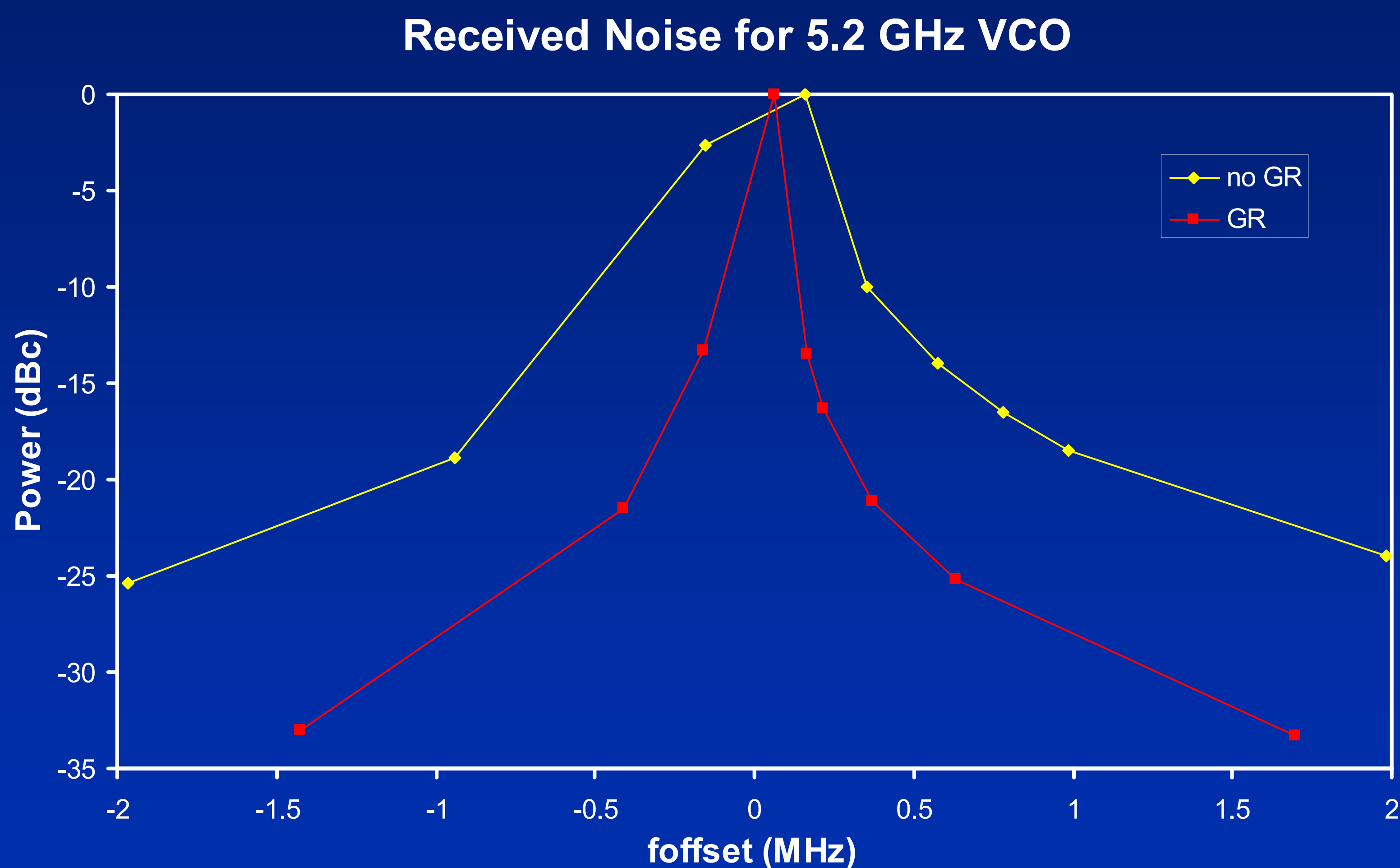


Resonant Gain Behavior



VCO Locking Range

$$f_{lock}^{[1]} \approx \frac{f_o}{2Q}\frac{I_{noise}}{I_{carrier}}$$

No GR/GR	*f_{center}*	*Locking Frequencies*	*Range*
No GR	4.3148 GHz	4.3145-4.315 GHz	50 kHz
GR	4.314 GHz	4.3137-4.3139 GHz	20 kHz

5.2 GHz VCO and Injection Locking

No GR/GR	*f_{center}*	*Locking Frequencies*	*Range*
No GR	2.027 GHz	2.0275-2.02755 GHz	50 kHz
GR	2.031 GHz	2.03065-2.03068 GHz	30 kHz

2.4 GHz VCO and Injection Locking

No GR/GR	*f_{center}*	*Locking Frequencies*	*Range*
No GR	812.89 MHz	812.9-812.905 MHz	5 kHz
GR	805.13 MHz	Doesn't Lock	-

900 MHz VCO and Injection Locking

Guard rings improve VCO locking

[1] (Razavi, JSSC, 39(9))

Conclusions

- Phase noise of a VCO is adversely affected by substrate noise
  - In extreme, VCO can lock to noise
- Bias current plays important role
- Guard rings are effective at lower frequencies, less useful at higher frequencies