

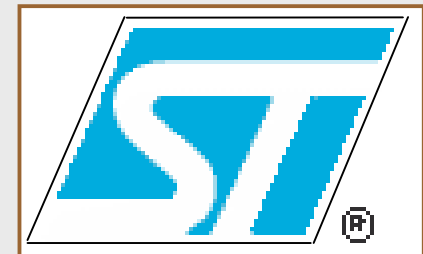
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Impact of Indirect Stability on Phase Noise Performance of Fully-integrated LC Tuned VCOs



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Outline

- Introduction:

SSCR performance of embedded oscillators

- AM-to-PM conversion

- Indirect stability

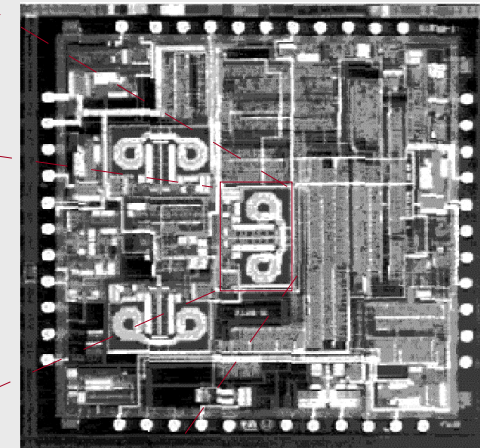
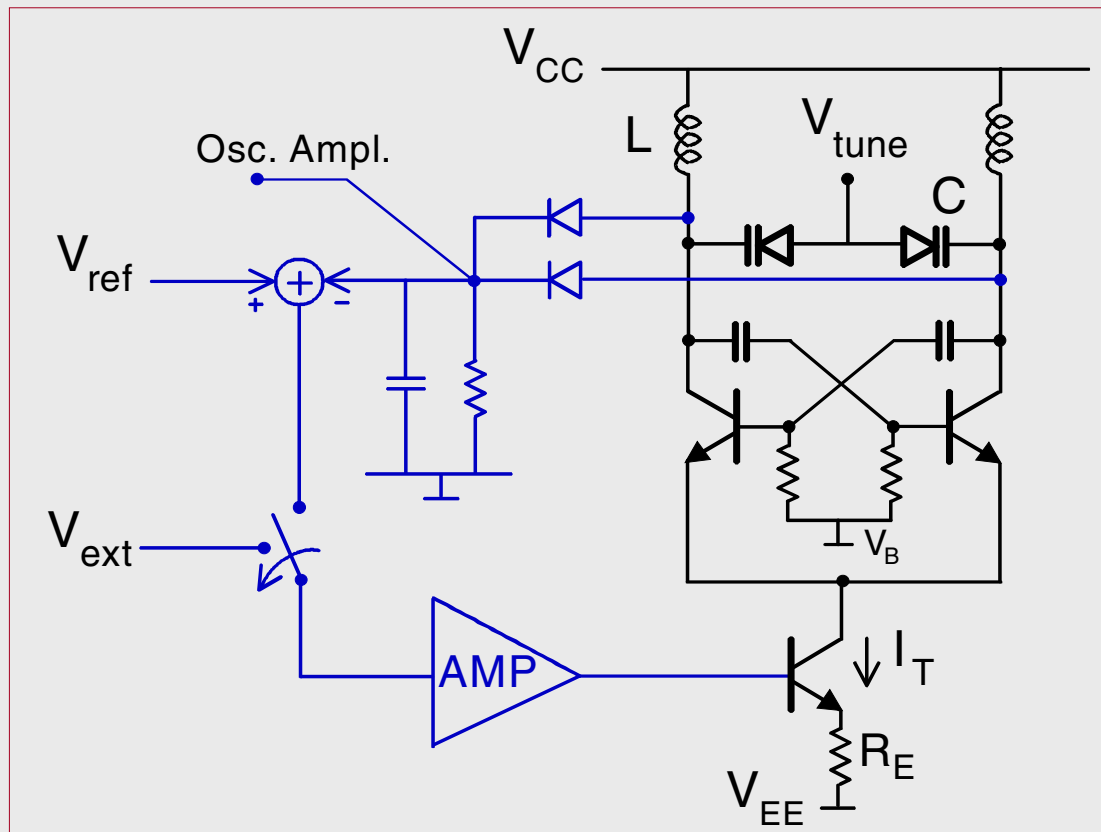
- Conclusions:

identification of the main *SSCR*-limiting effects

Introduction:

SSCR Performance in Embedded VCO

VCO Structure

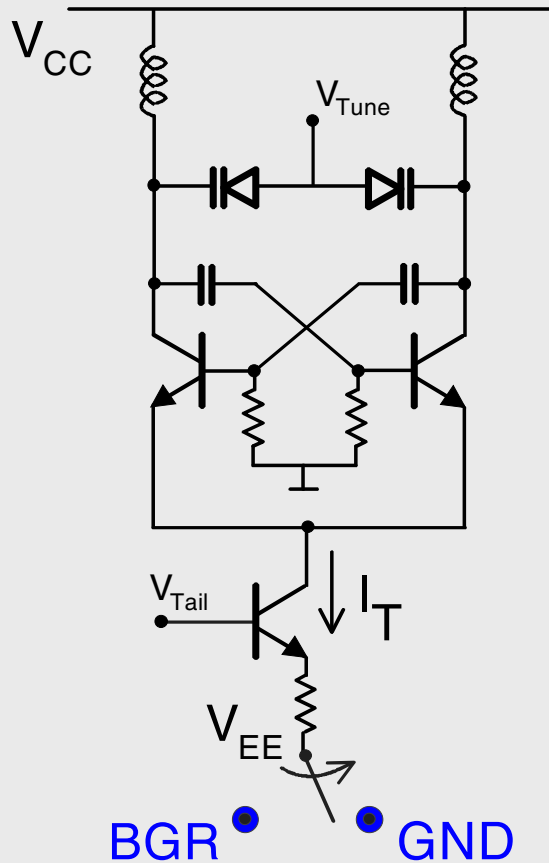


$$f_0 = 2.6 \text{ GHz}$$

$$Q = 10$$

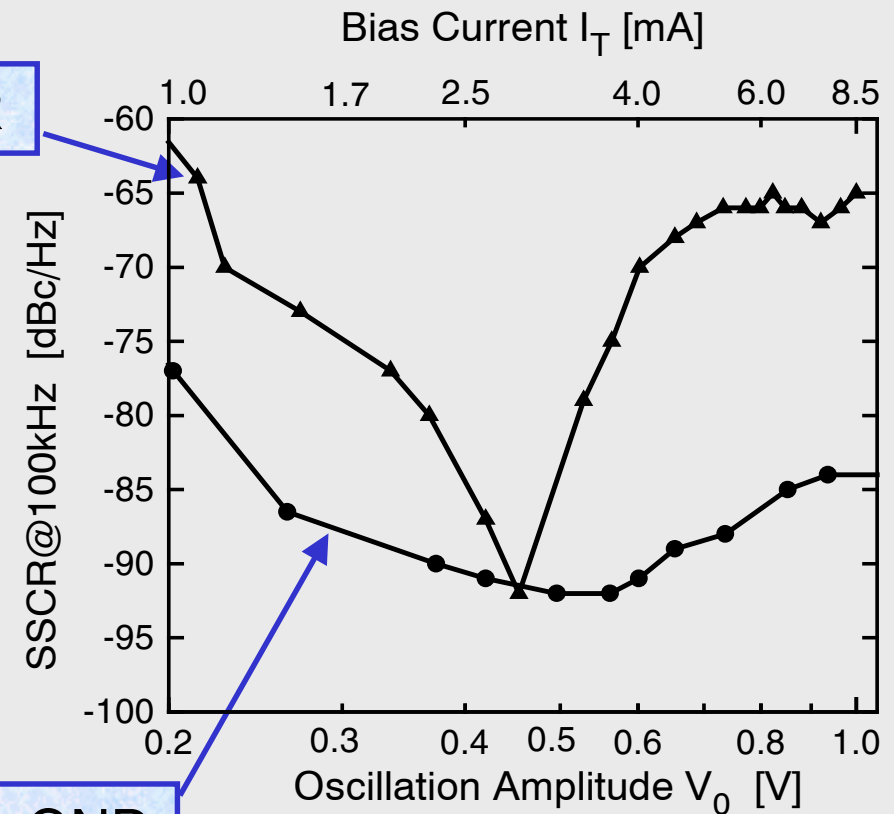
$$L = 680 \text{ pH}$$

SSCR Vs. Oscillation Amplitude

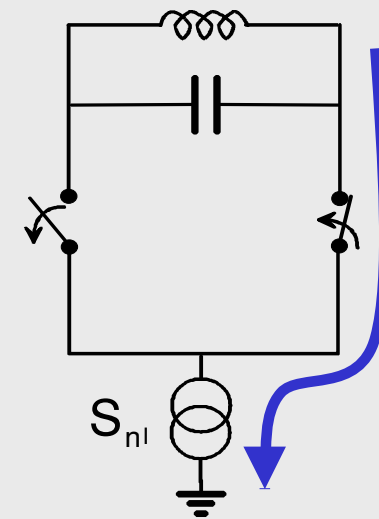
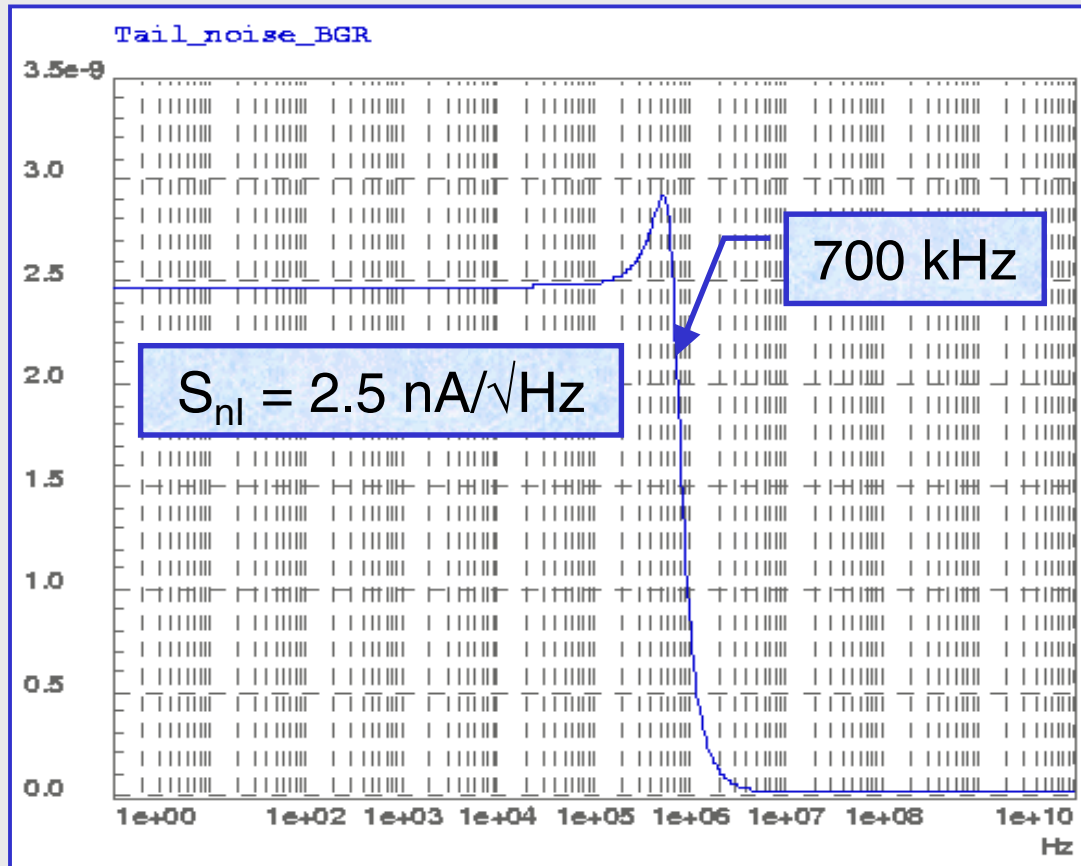


V_{EE} to BGR

V_{EE} to GND



Noise From BandGap Reference

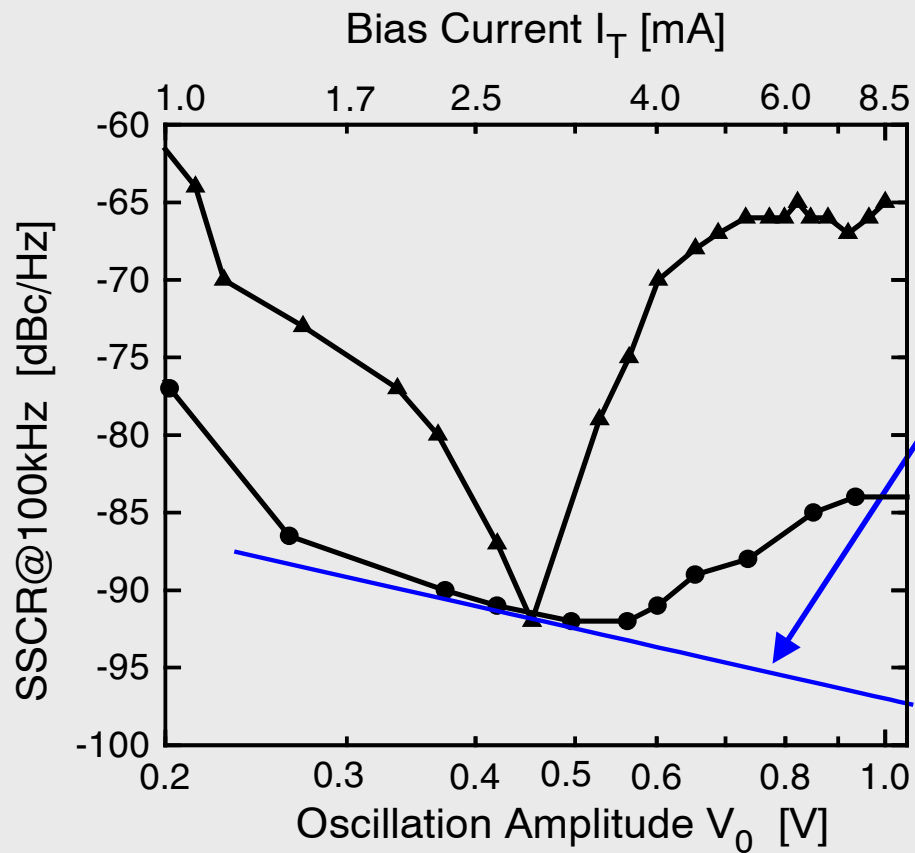


Low-frequency noise



Only AM at the output

Non-linear Noise Transfer



$$\frac{1}{2} \frac{kT}{C} \frac{\omega_0}{Q} \frac{1}{\alpha^2} (1+F) \bigg/ \frac{V_0^2}{2}$$

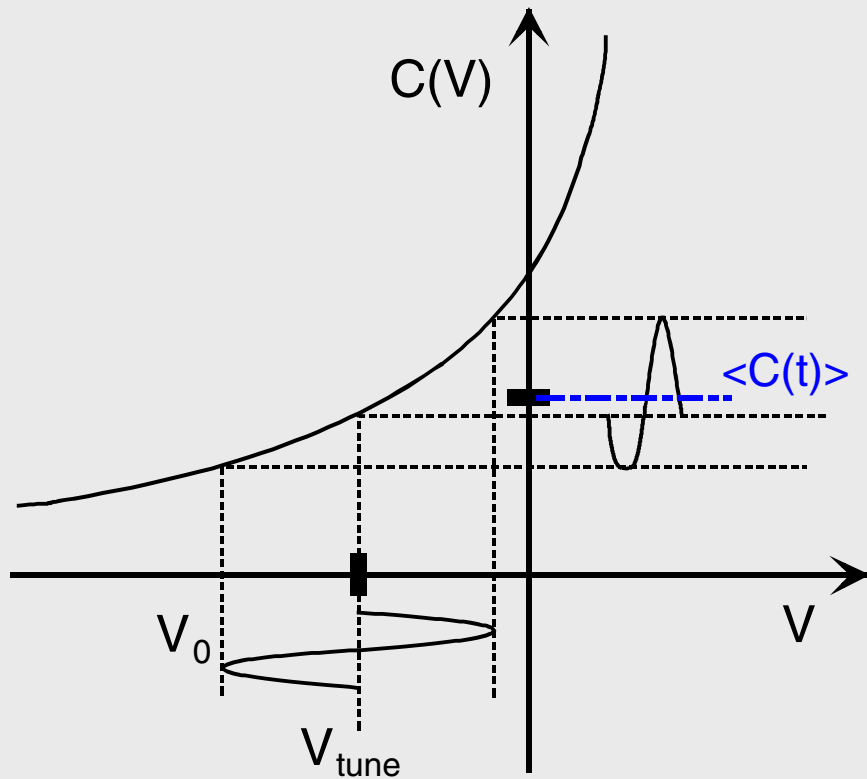
$$\alpha = 2\pi \cdot 100 \text{ kHz}$$

A Mechanism to Be Investigated

- Low-frequency noise from the tail
affects the *SSCR*
- Sensitivity to tail disturbances
raises with oscillation amplitude

AM-to-PM Conversion

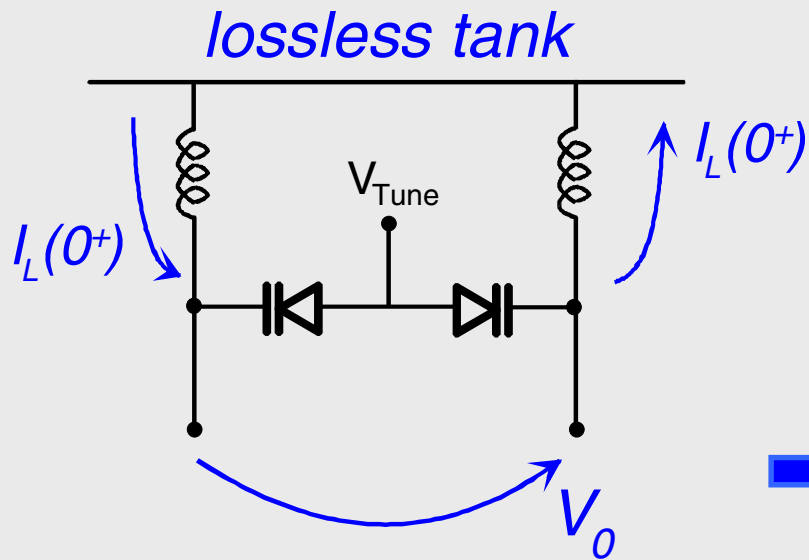
An Intuitive Model



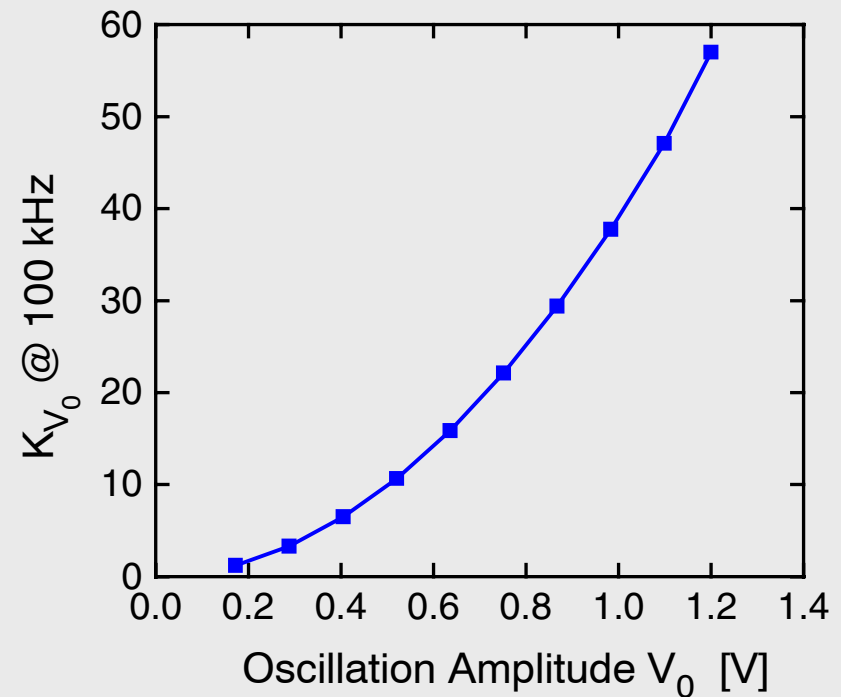
$$\omega_0 \cong \frac{1}{\sqrt{L \langle C(t) \rangle}}$$

- ω_0 depends on the amplitude
- AM \rightarrow PM
- Rigorous analysis performed by simulation

After Simulation

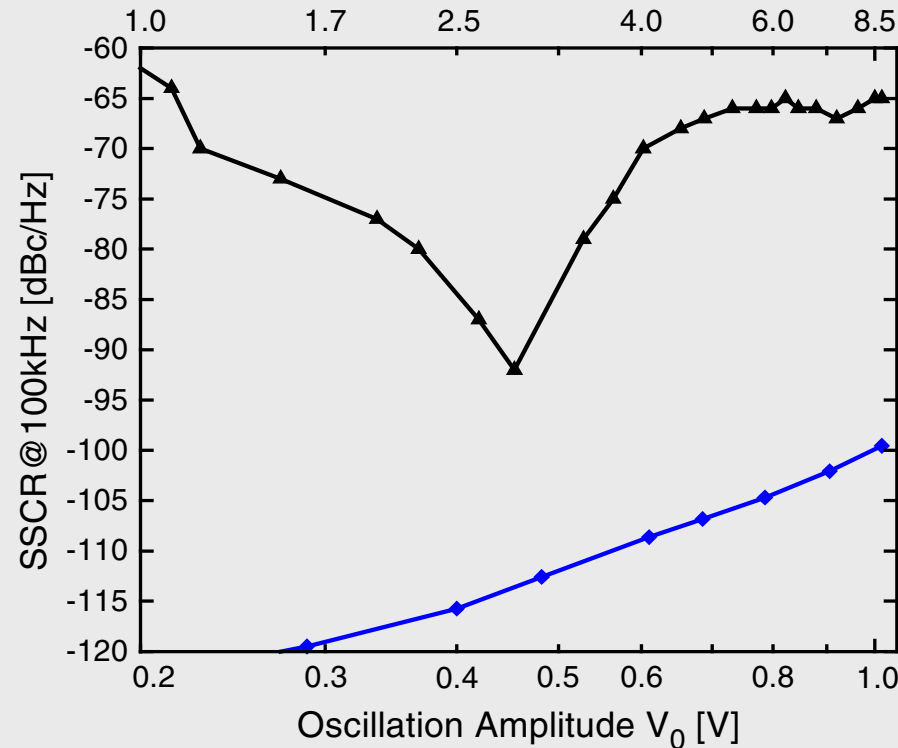


$$K_{V_0} = \frac{1}{\alpha} \left| \frac{\partial \omega_0}{\partial V_0} \right| V_0$$



AM-to-PM Conversion Is Not the Limit

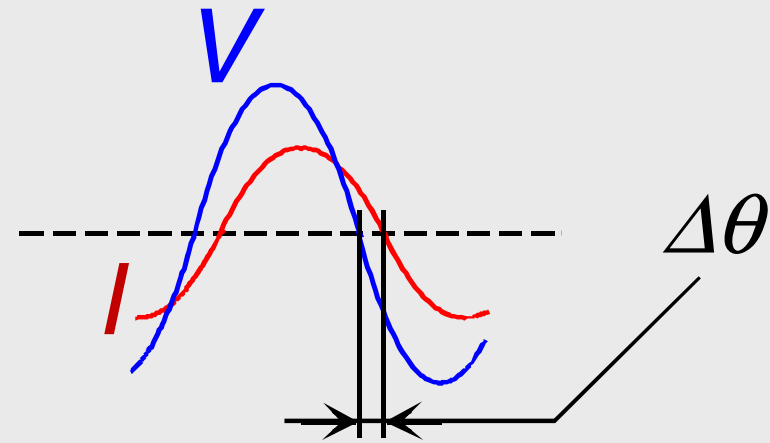
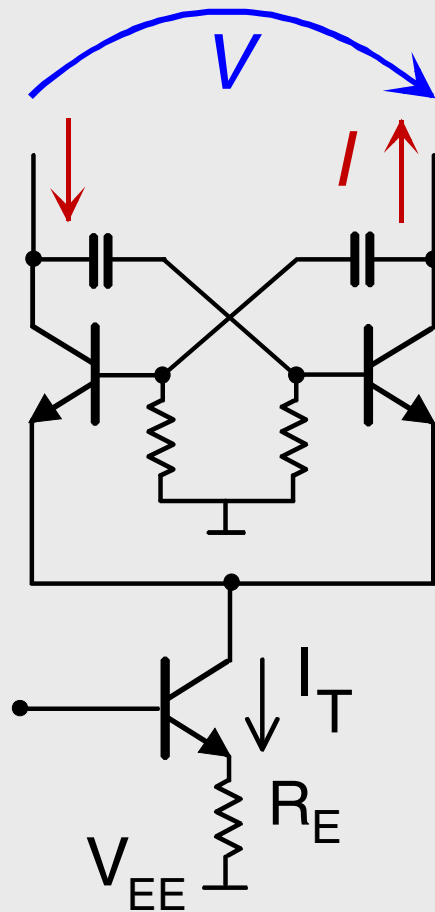
$$SSCR @ 100 \text{ kHz} = \frac{1}{2} \cdot \frac{K_{V_0}^2}{V_0^2} \cdot S_{nV_0}(\alpha) \rightarrow -100 \text{ dBc/Hz @ 1V}$$



Effect of the Transconductor

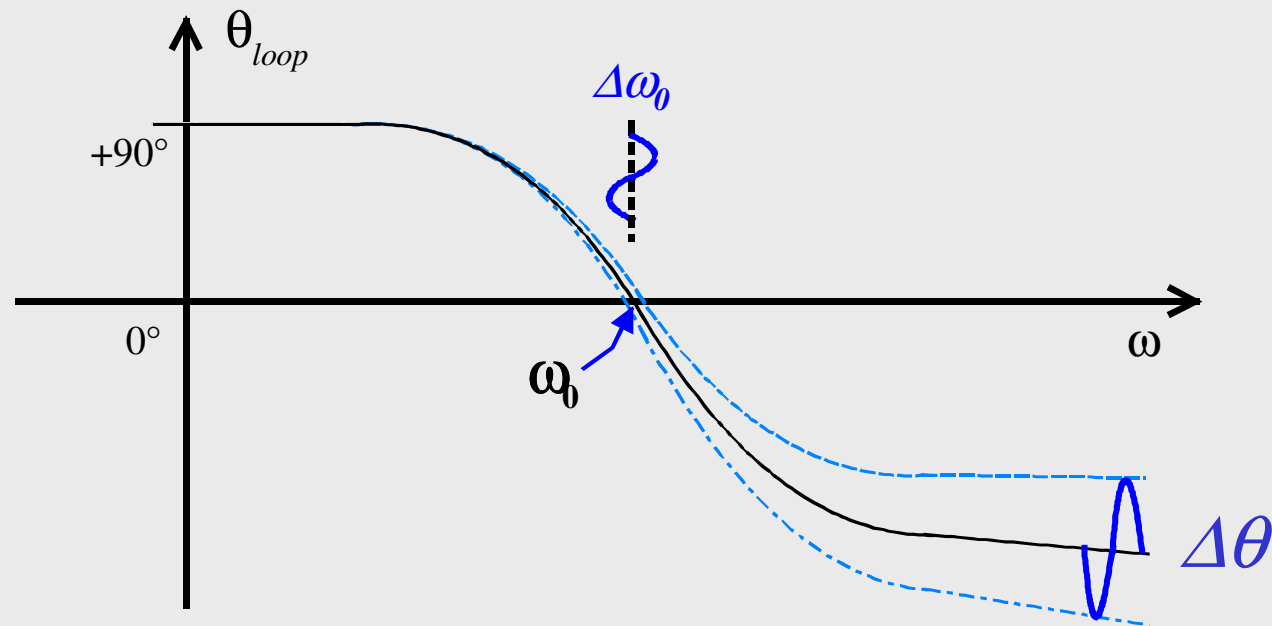
(Indirect Stability)

Transconductor



- Additional phase shift due to the transconductor

Indirect Stability



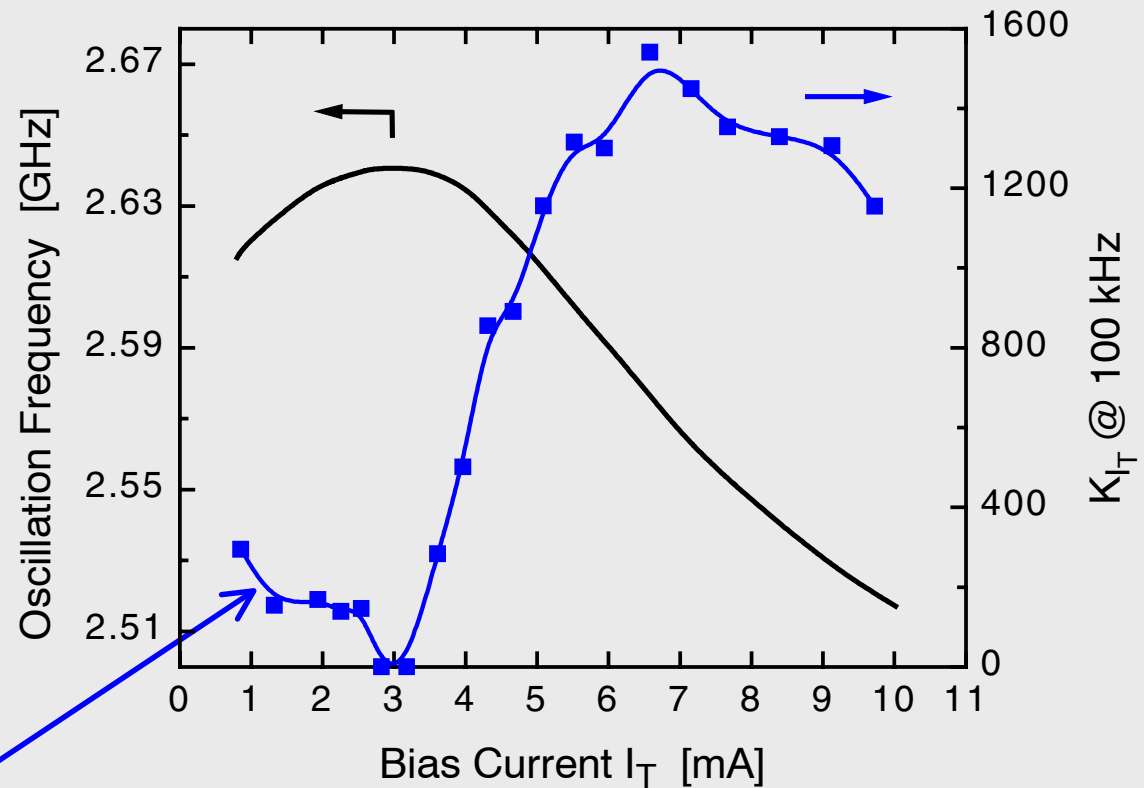
$$\omega \cong \frac{1}{\sqrt{LC}} \left[1 - \frac{\Delta\theta}{2Q} \right]$$

- Dependent on the bias current

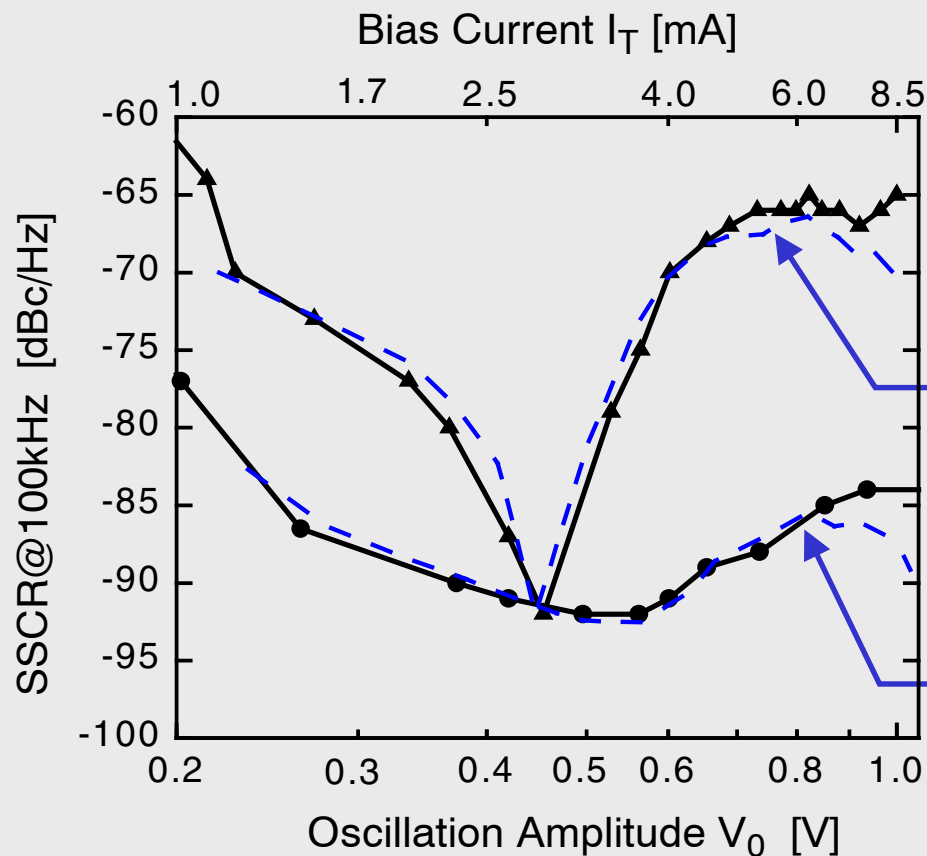
Experimental Verification

$$\omega_0(I_T) \rightarrow K_{I_T}$$

$$K_{I_T} = \frac{1}{\alpha} \left| \frac{\partial \omega_0}{\partial I_T} \right| I_T$$



Fitting of Experimental Data

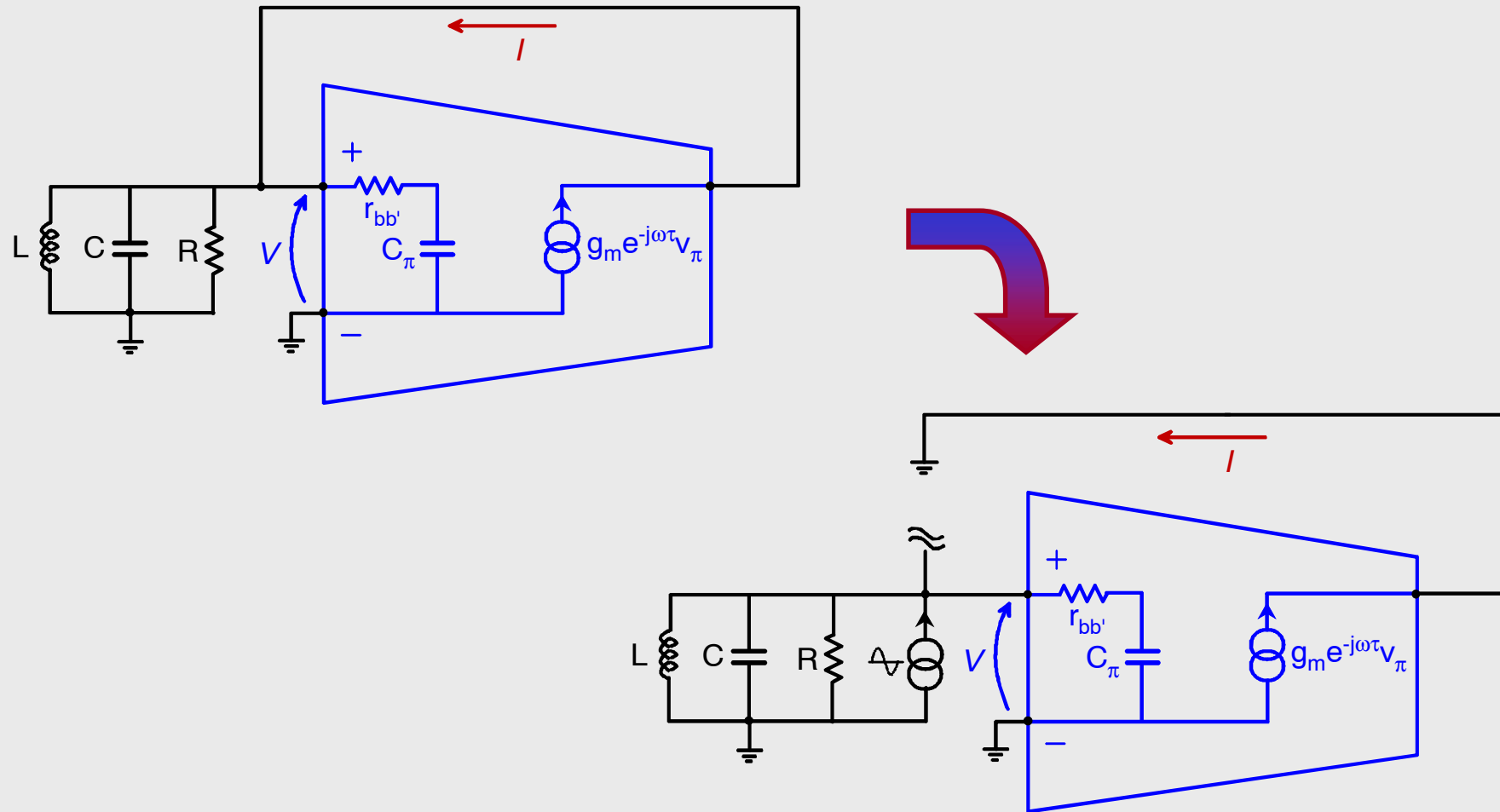


$$SSCR = \frac{I}{2} \cdot |K_{I_T}|^2 \cdot \frac{S_{I_T}(\alpha)}{I_T^2}$$

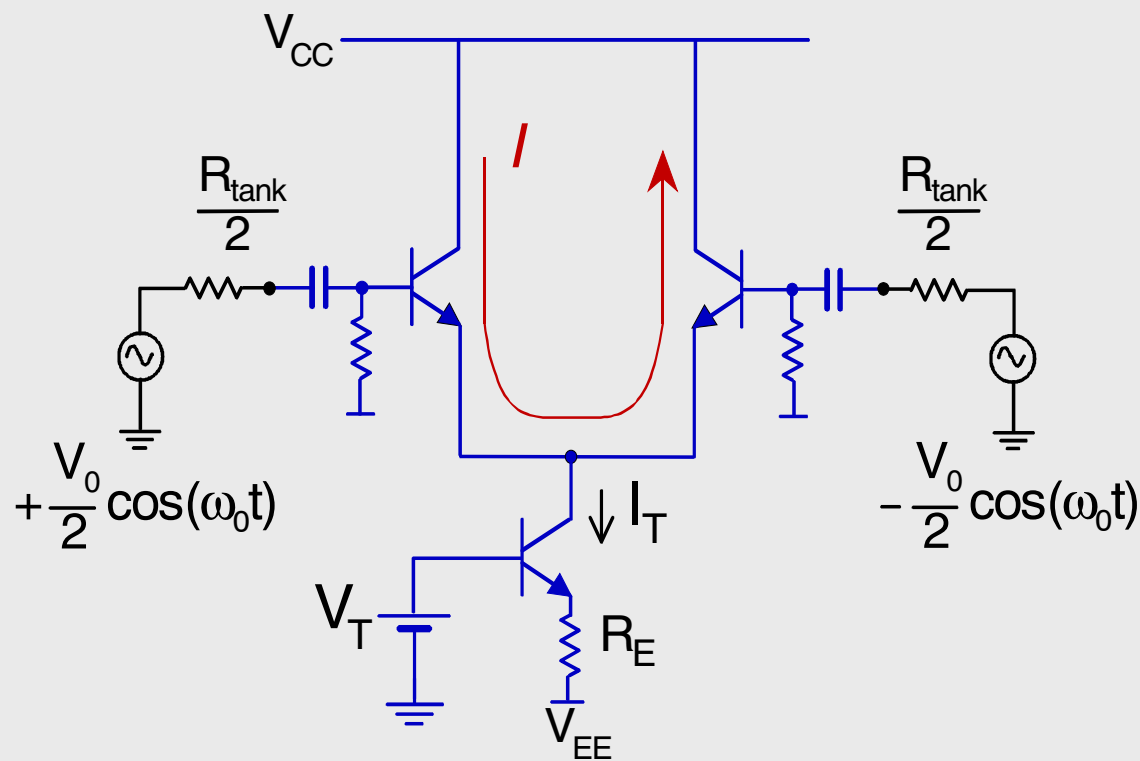
with BGR noise
 $S_{I_T} = 2.56 \text{ (nA)}^2/\text{Hz}$

with measured noise
 $S_{I_T} = 0.09 \text{ (nA)}^2/\text{Hz}$

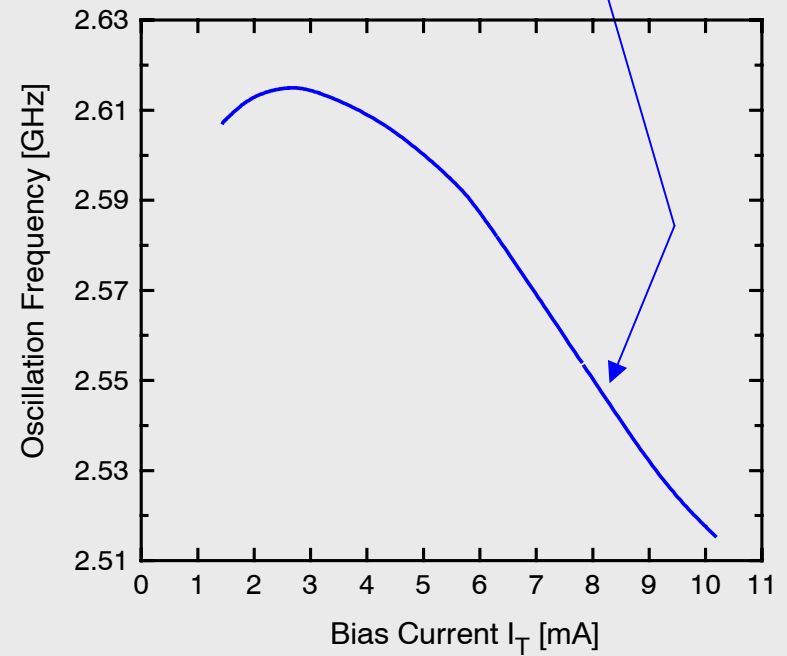
Loop Delay Evaluation by Simulation



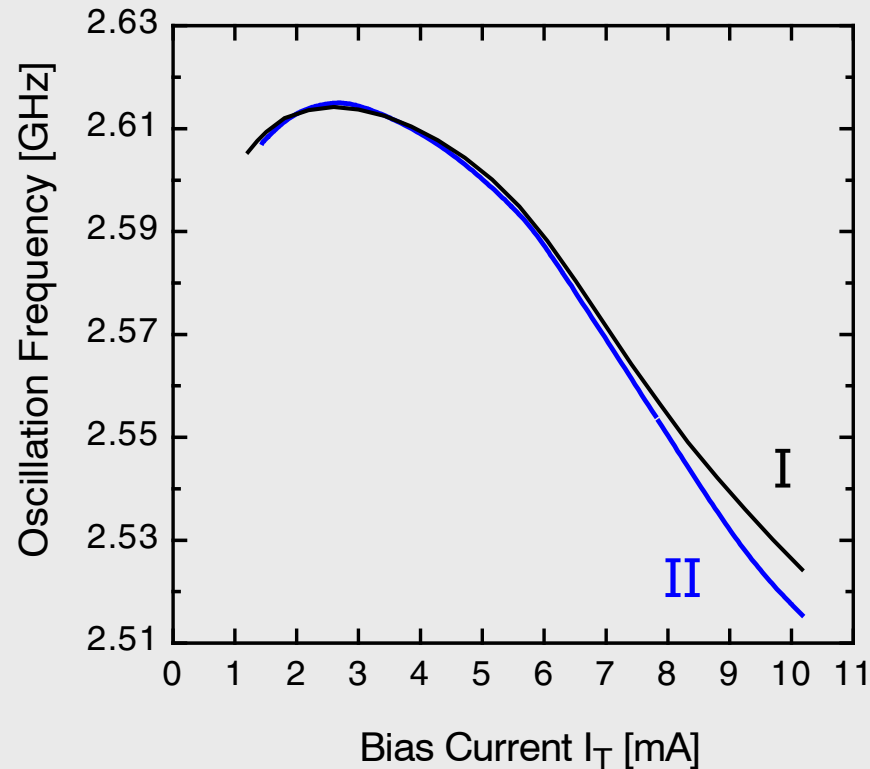
Open-Loop Technique



$$\omega \cong \frac{1}{\sqrt{LC}} \left[1 - \frac{\Delta\theta}{2Q} \right]$$



Evidence of Indirect Stability

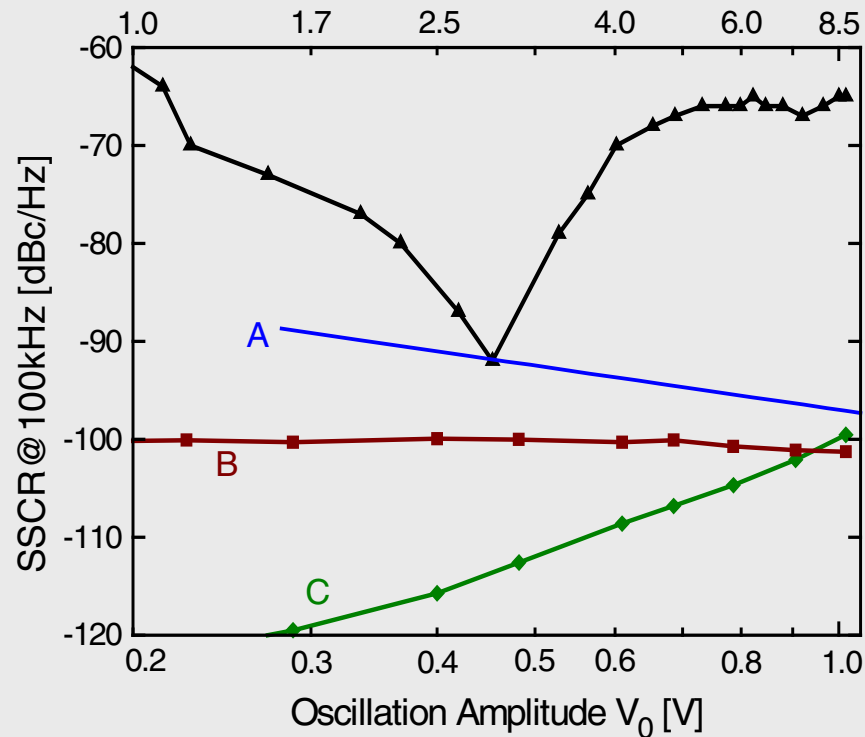


- Curve (I) derived by sweeping I_T in closed-loop simulations
- Frequency shift mainly due to phase loop delay modulation

Conclusions

Identification of the main *SSCR*-limiting effects

Conclusions



- *AM-to-PM conversion and indirect stability limit SSCR*
- Noise can modulate the loop delay leading to additional phase noise
- Common-mode low-frequency noise (e.g. BGR, AAC, substrate) is “converted” into phase noise
- The impact of this effect increases with the amplitude