CHALMERS

MILLIMETRE-WAVE GALLIUM NITRIDE SIGNAL SOURCE DESIGN

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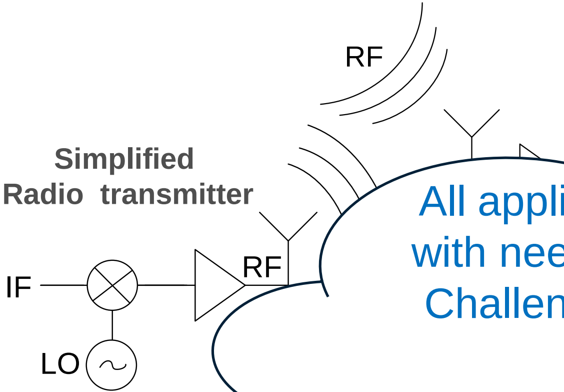
OUTLINE

- Motivation and challenges:
  - Why Signal sources and why in GaN technology
- Design of a GaN signal source:
  - Some fundamental oscillator design and a specific GaN example
- Some design examples and GRACE specific work

COMMUNICATION AND SENSORS

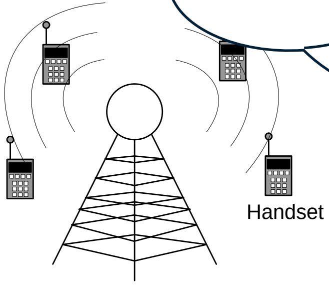


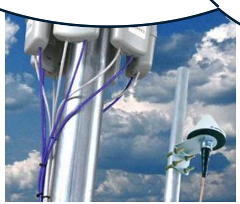
Communication links!

All applications move up in frequency
with need for new electronic hardware
Challenges change due to increased
bandwidth available

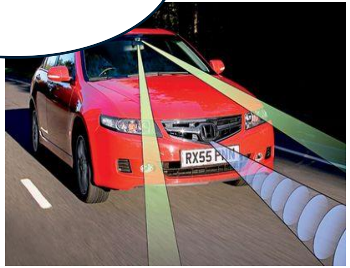
Phase noise is the main challenge in a
signal source

Radio base statio





obile access, WIFI, GPS, Radar)



PROBLEM I: STRONG BLOCKER

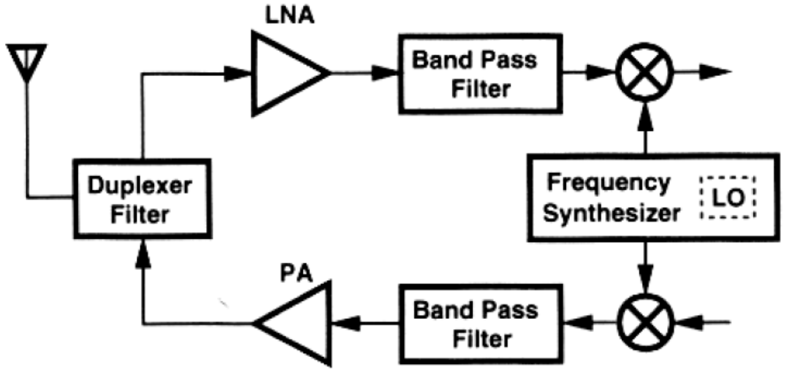
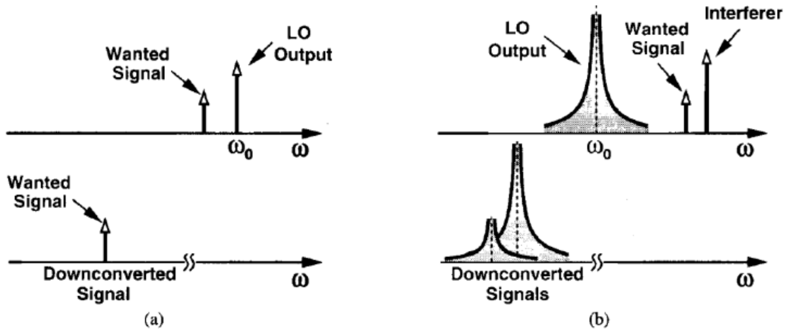


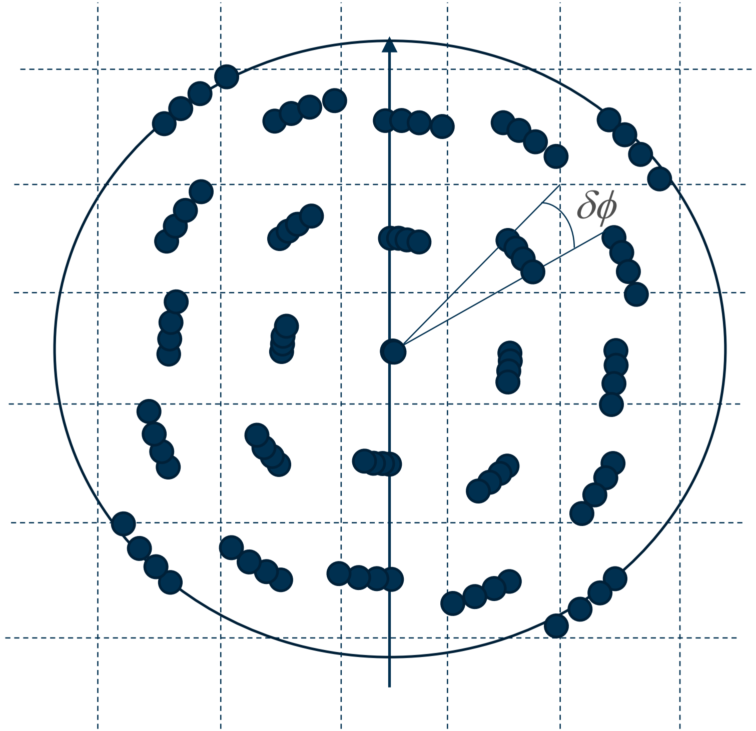
Figure 7.12 Generic transceiver front end.

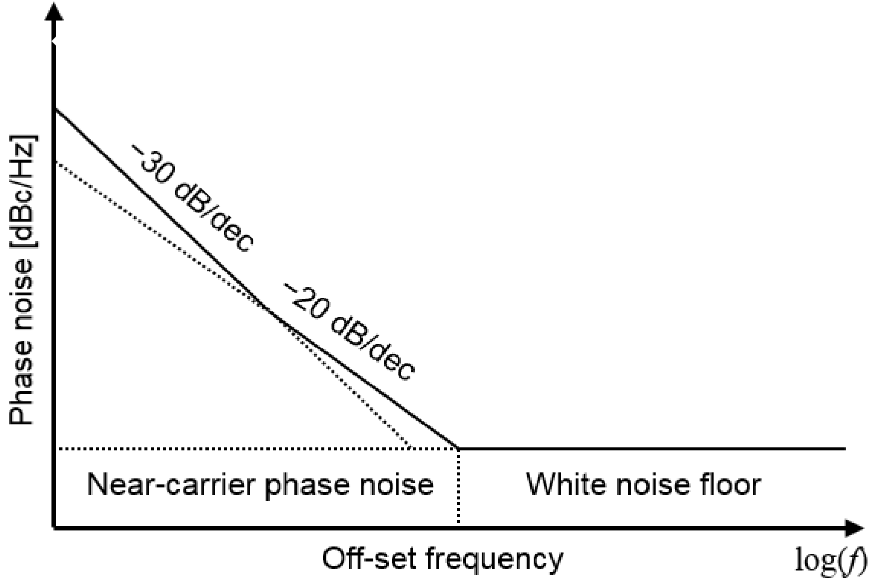
Communication <u>without</u> phase noise

Communication <u>with</u> phase noise and strong interferer

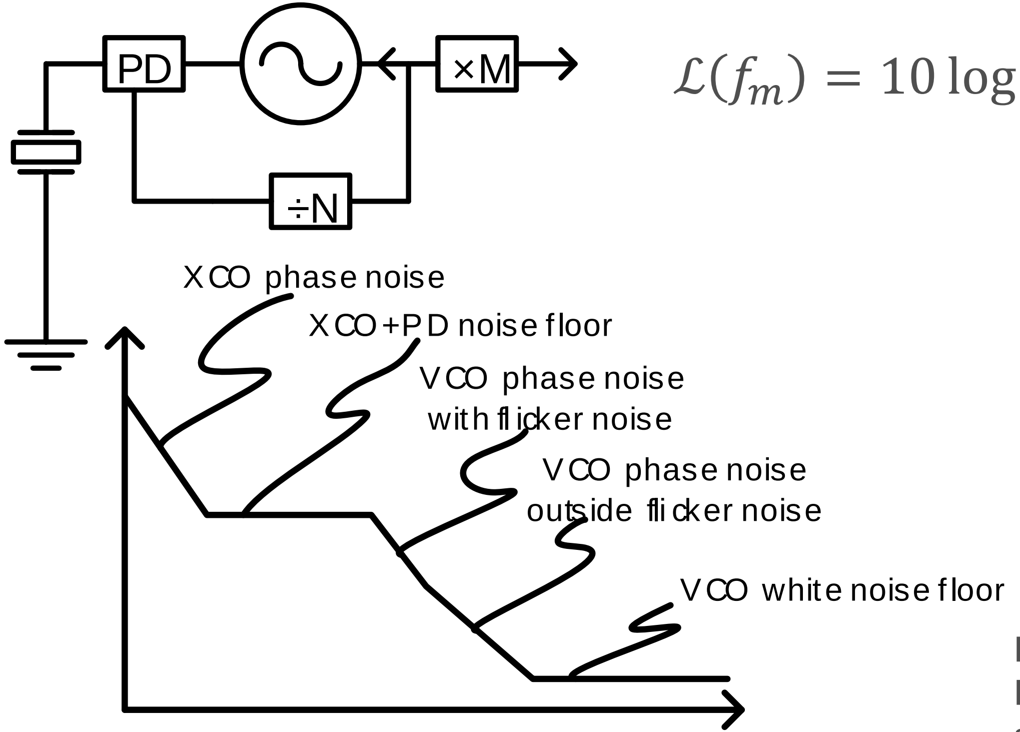


PROBLEM II: LIMITED CAPACITY





LO NOISE LIMITATIONS

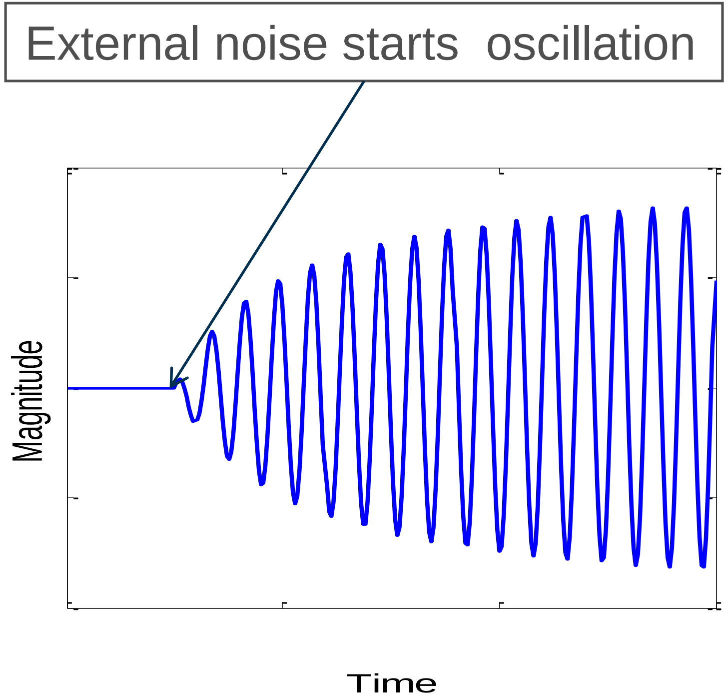


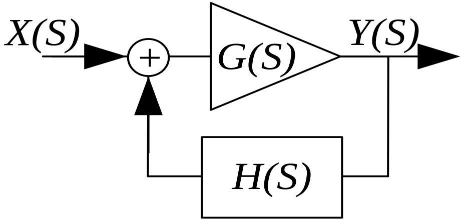
$$\mathcal{L}(f_m) = 10\log_{10}\left\{\frac{FkT}{2P_{sig}}\left[1+\left(\frac{f_0}{2Qf_m}\right)^2\right]\left(1+\frac{f_{1/f^3}}{f_m}\right)\right\}$$

- Increased Q factor
  - 20log(Q2/Q1) improvement in VCO phase noise but not noise floor
- Increased oscillation frequency
  - 20log(M2/M1) outside loop bandwidth including noise floor
- Increased power
  - 10log(P2/P1) improvement in VCO phase noise and noise floor

High frequency, High power, good Q desired☺
Far carrier noise limit capacity of wideband signals -------> Oscillators in GaN

TRANSIENT RESPONSE OF OSCILLATOR





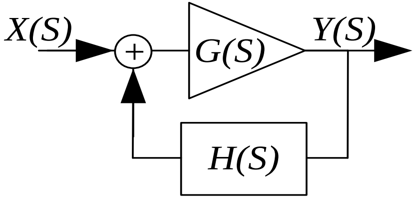
$$Y(s)=\frac{G(s)}{1-GH(s)}X(s)$$

$$1-GH(s)=0$$

- Amplitude grows until saturation
- Eventually steady state is reached
  - where variations in frequency and amplitude are small
  - Frequency variations are known as jitter or phase noise

REPRESENATION OF AN OSCILLATOR

Feed-back view



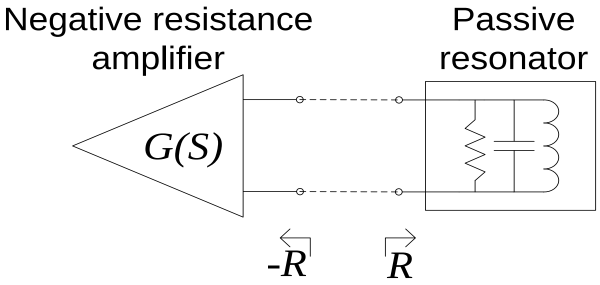
$$Y(S) = X(S)\frac{G(S)}{1-G(S)H(S)}$$

Positive feedback amplifier with infinite gain if

***1-G(s)H(s)*=0** **(1)**

At a frequency where (1) is fulfilled, any little energy injection will spontaneously start an oscillation

Negative resistance



$$X_{in}(I_0, j\omega_0) + X_L(j\omega_0) = 0$$

$$R_{in}(I_0, j\omega_0) + R_L = 0$$

A passive resonator determines the oscillation frequency

Active circuitry (reflection amplifier/ negative resistance)
injects energy to compensate losses in the resonator

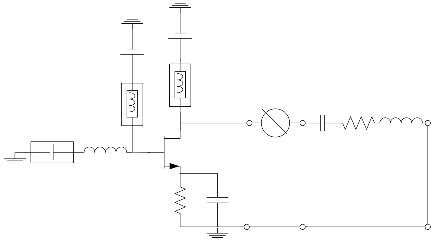
OSCILLATOR TOPOLOGY

Oscillator topology means in what way the electrical components are arranged to form the oscillator

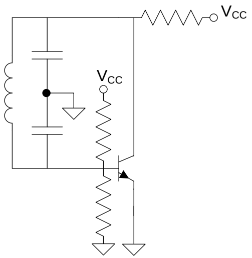
- differ primarily in the feedback arrangement, the way the signal is coupled between active device and resonator

Single-ended oscillators

Negative resistance

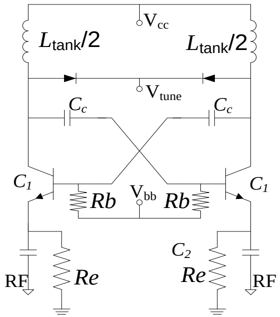


Tapped feedback

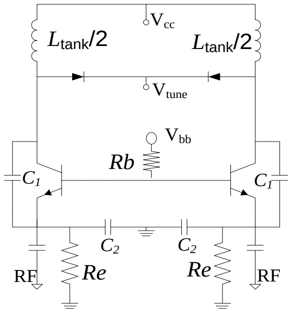


Balanced (differential) oscillators

Cross-coupled



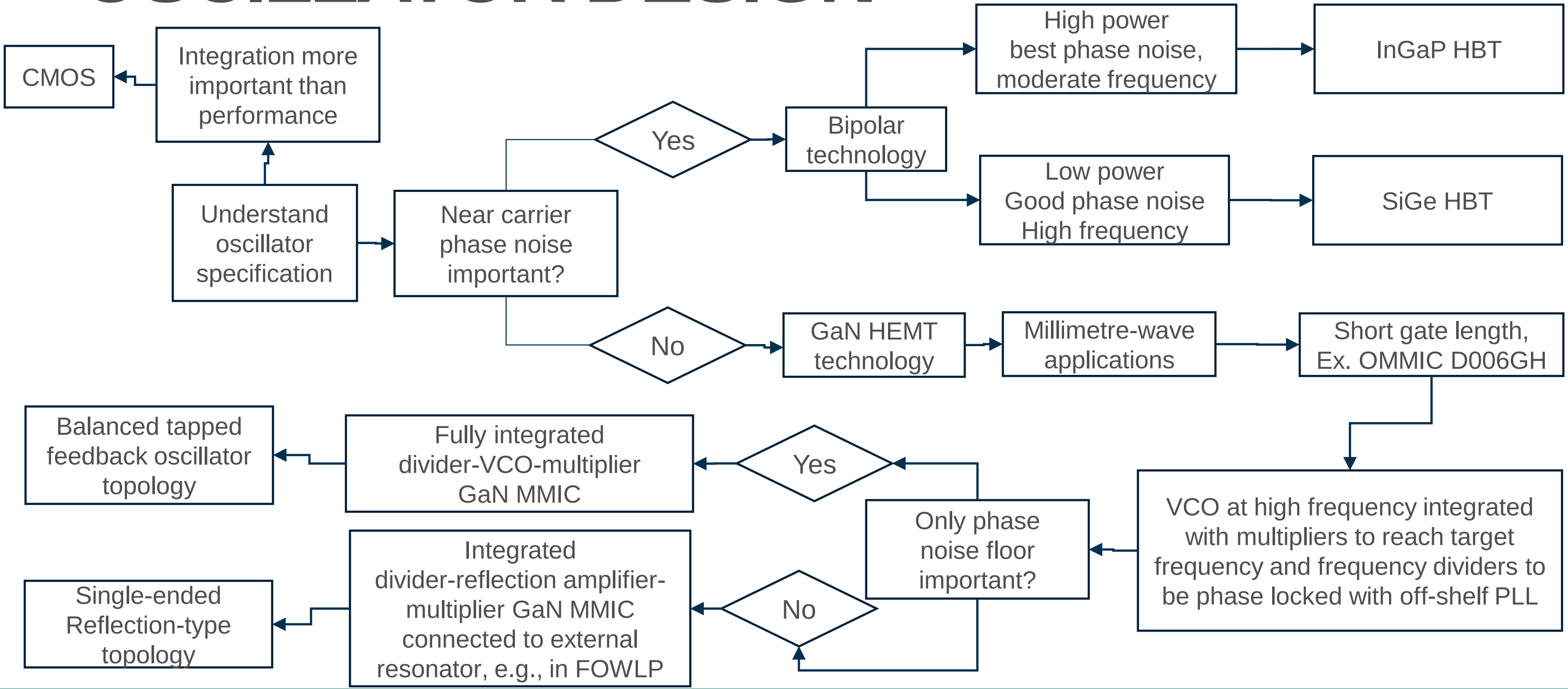
Balanced Colpitts



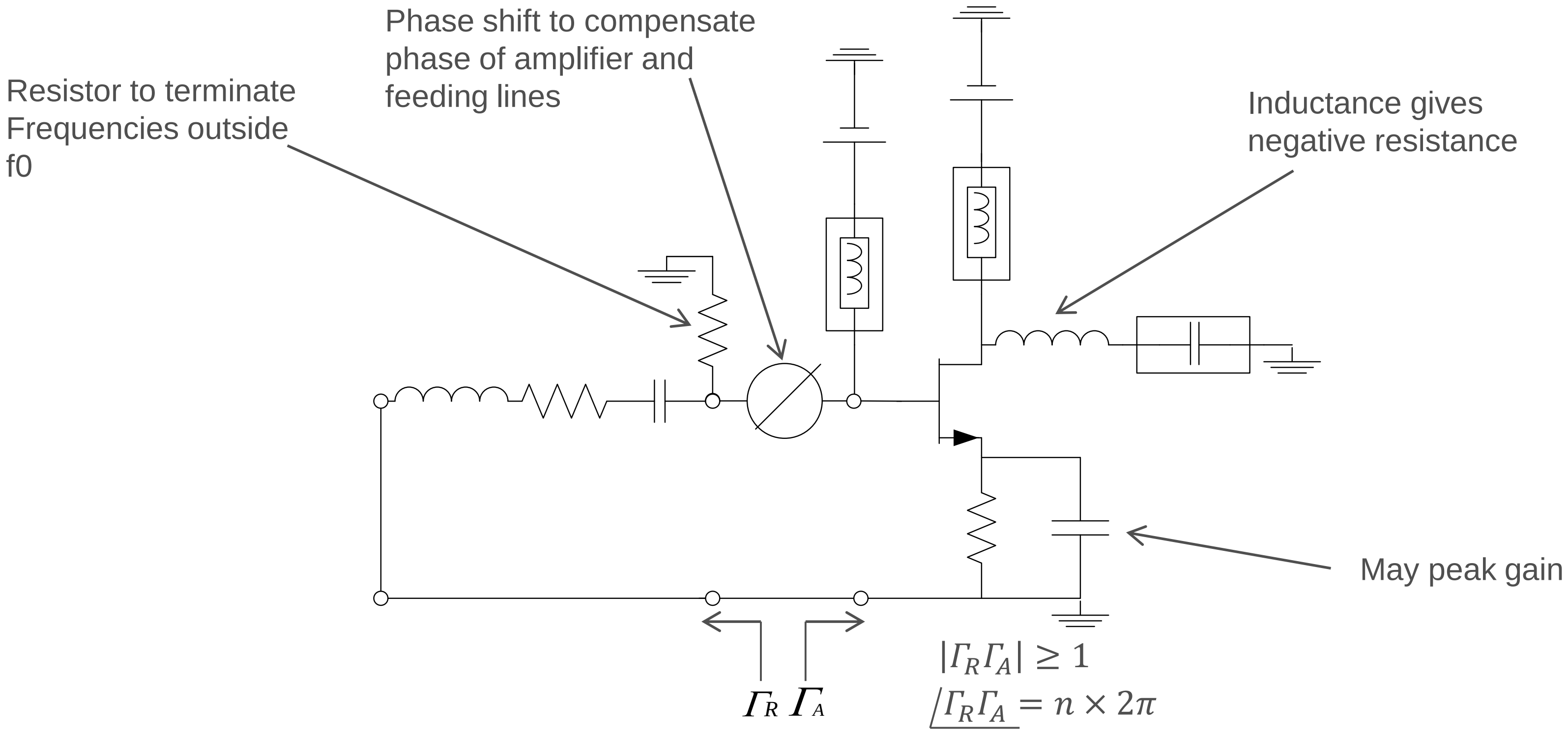
Several different topologies can give good phase noise if they are well designed

- Some are difficult to tune
- May also be suitable for different technologies

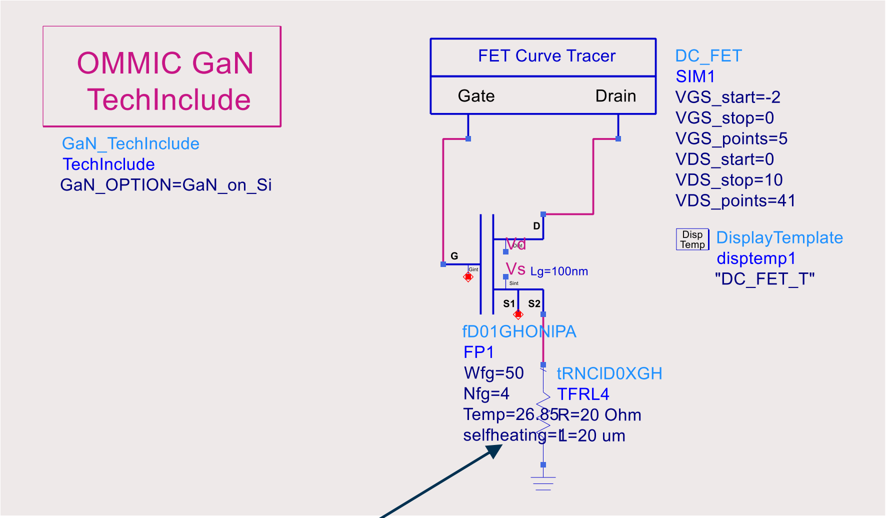
OSCILLATOR DESIGN



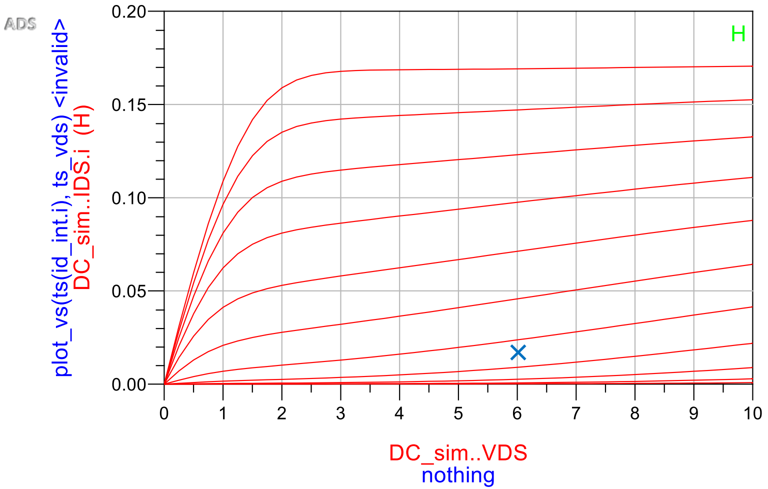
GAN HEMT REFLECTION TYPE OSCILLATOR



I: SELECT DEVICE AND RUN DC SIMULATION

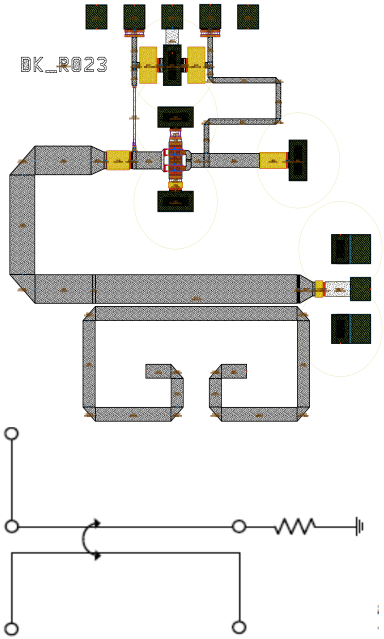


Source resistor
included in simulation

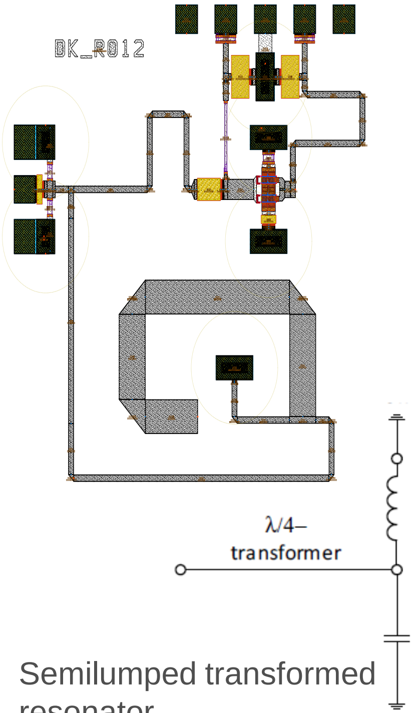


Choose quiescent point
Class AB operation
Moderate Vds to reduce noise

II: DESIGN RESONATOR

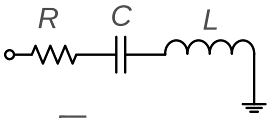


Coupled half-wave resonator



Semilumped transformed resonator

- Suitable resonator topologies depend on frequency and technology
- All may be approximated as simple series resonator
- Design challenge is to maximize Q and obtain a reasonable R that can be coupled to reflection amplifier

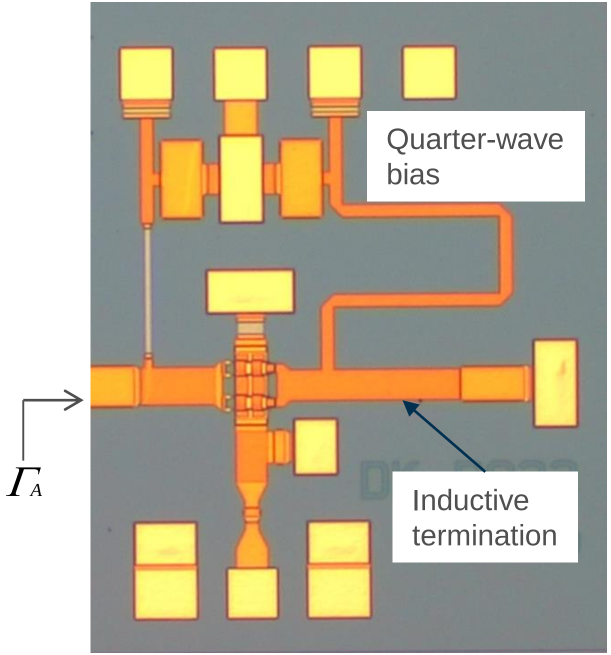


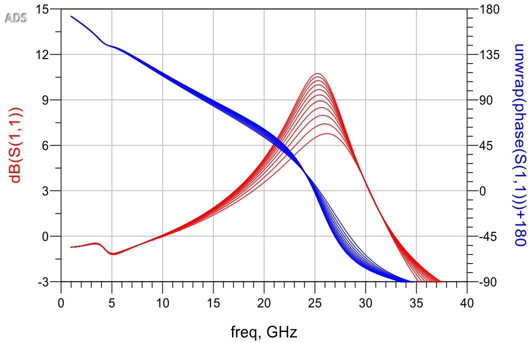
$$Q = \frac{\omega_0 L}{R} = \frac{1}{R\omega_0 C}$$

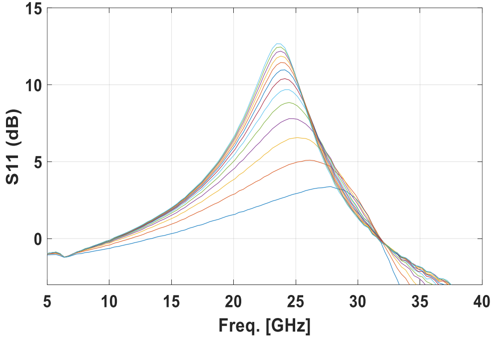
$$= \frac{1}{R}\sqrt{\frac{L}{C}} \Longrightarrow R = \frac{1}{Q}\sqrt{\frac{L}{C}}$$

- A resistance of 5-20 ohm to reflection amplifier is equivalent to about 2-7 dB resonator loss which meets a gain of 5-10 dB from reflection amplifier

III: DESIGN REFLECTION AMPLIFIER

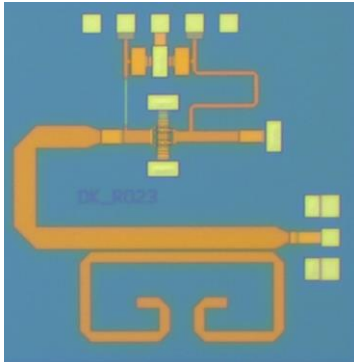




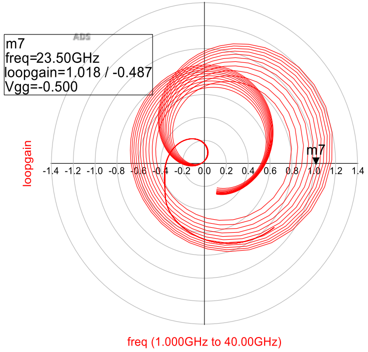


Measured reflection gain slightly higher than simulated

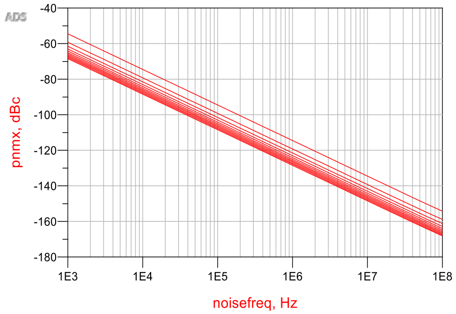
IV: COMPLETE OSCILLATOR

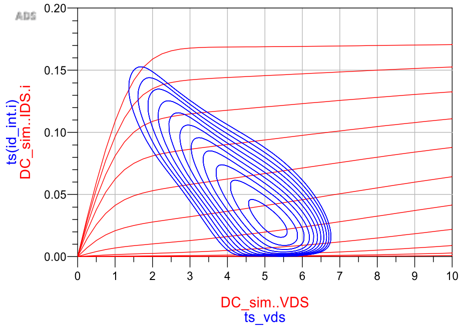


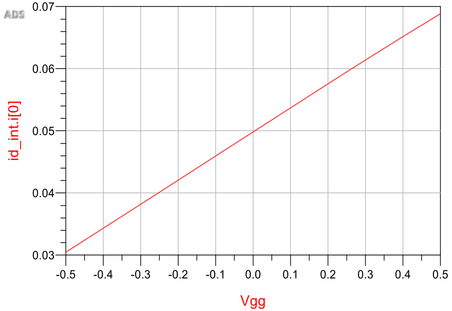
Small-signal open loop gain

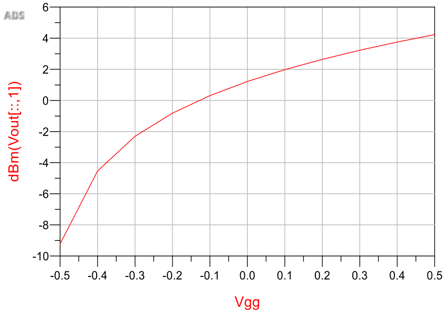


Phase noise and output power from harmonic balance

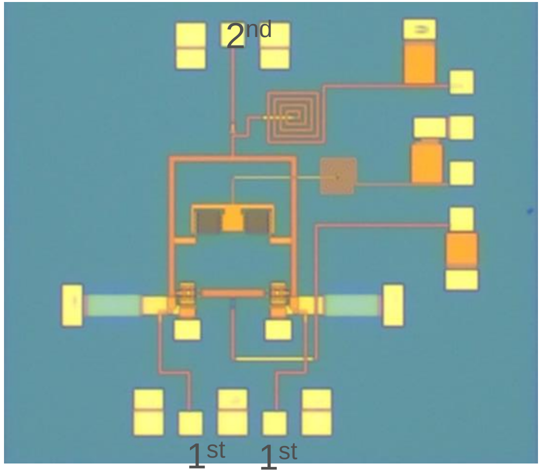


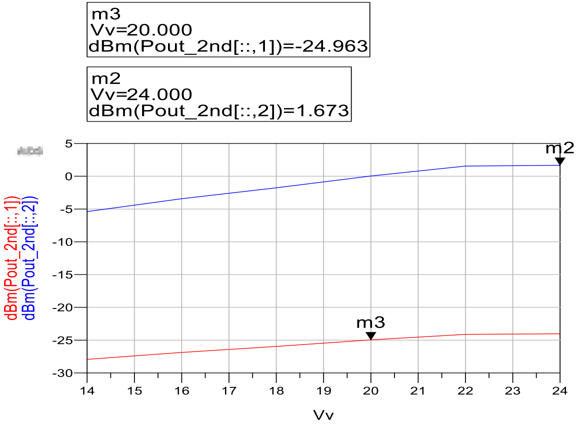


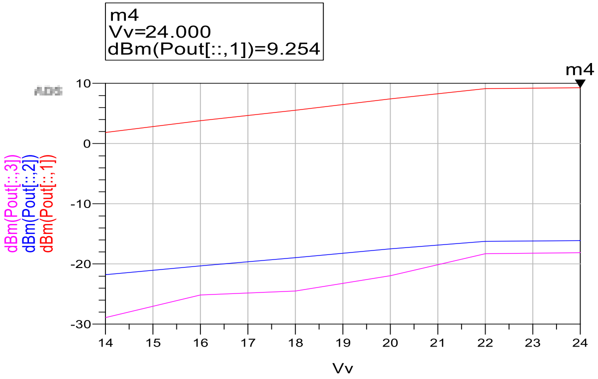




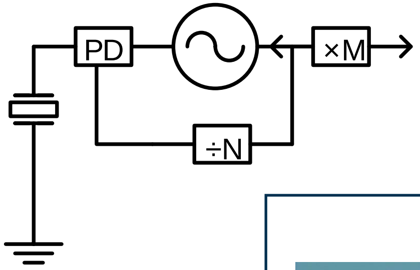
BALANCED COLPITTS VCO



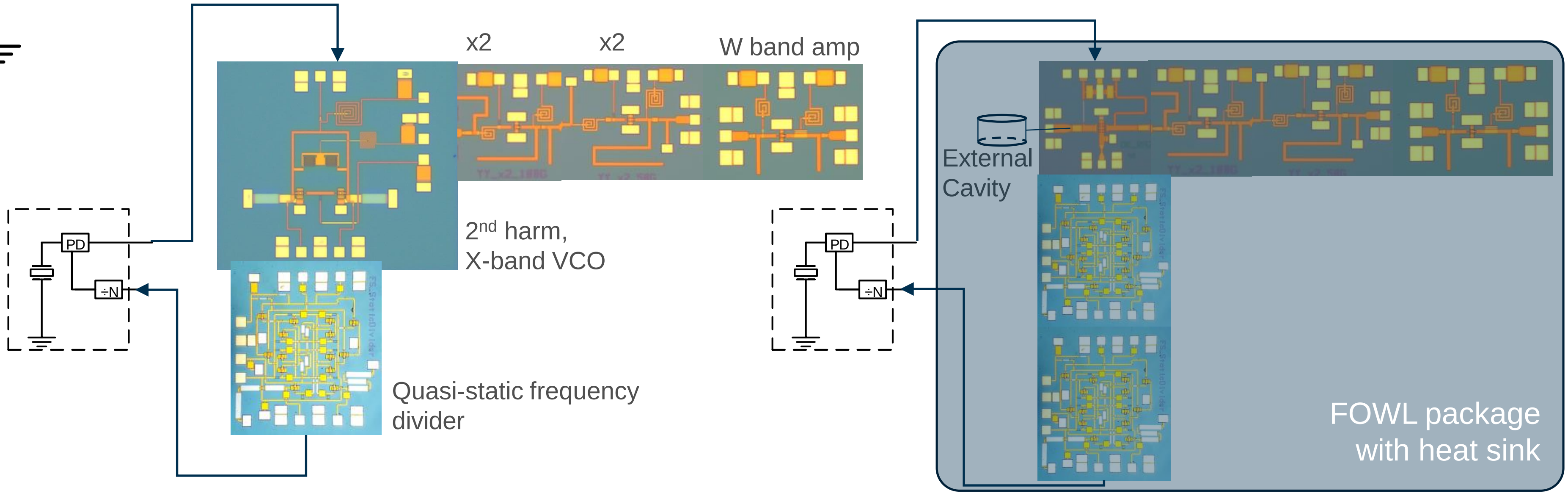




NOT ONLY ABOUT VCO



The goal of GRACE project is to integrate VCOs, frequency multipliers and frequency divider to form an ultra-low noise W-band source



SUMMARY

- Millimetre-wave low noise floor LO generation critical in future communication and sensor systems
- Short gate length GaN HEMT technology suitable in terms of operation frequency and power capacity.
- VCO, frequency multiplier and frequency divider integrated on one MMIC coupled to external PLL circuit