SiGe based Multiple-phase VCO Operating for mm-Wave Frequencies

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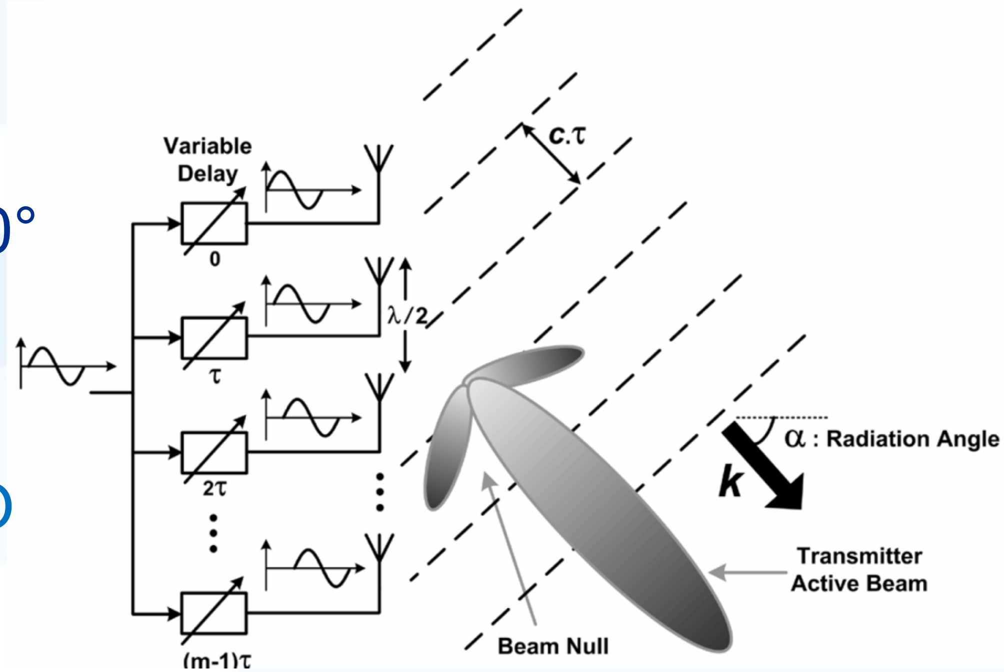
mm-Wave systems

- Unlicensed spectrum – 7 GHz bandwidth available at 60 GHz
- Short range communication - specific attenuation characteristics 10-15 dB/km
- Highly advanced Silicon integrated circuit technology
- Reduced antenna size – **phased arrays**

Phased arrays

- Number of antenna elements
- Narrow-band systems
  Phase control range = 360°
  Phase resolution = 22.5°
- Phase shift @ RF, IF or LO



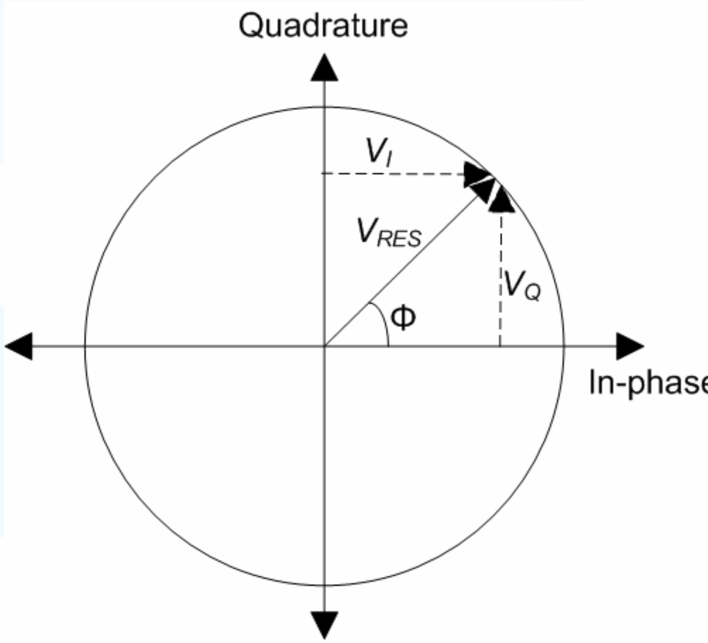
Phased array transmitter [1]

Integrated phase shifter

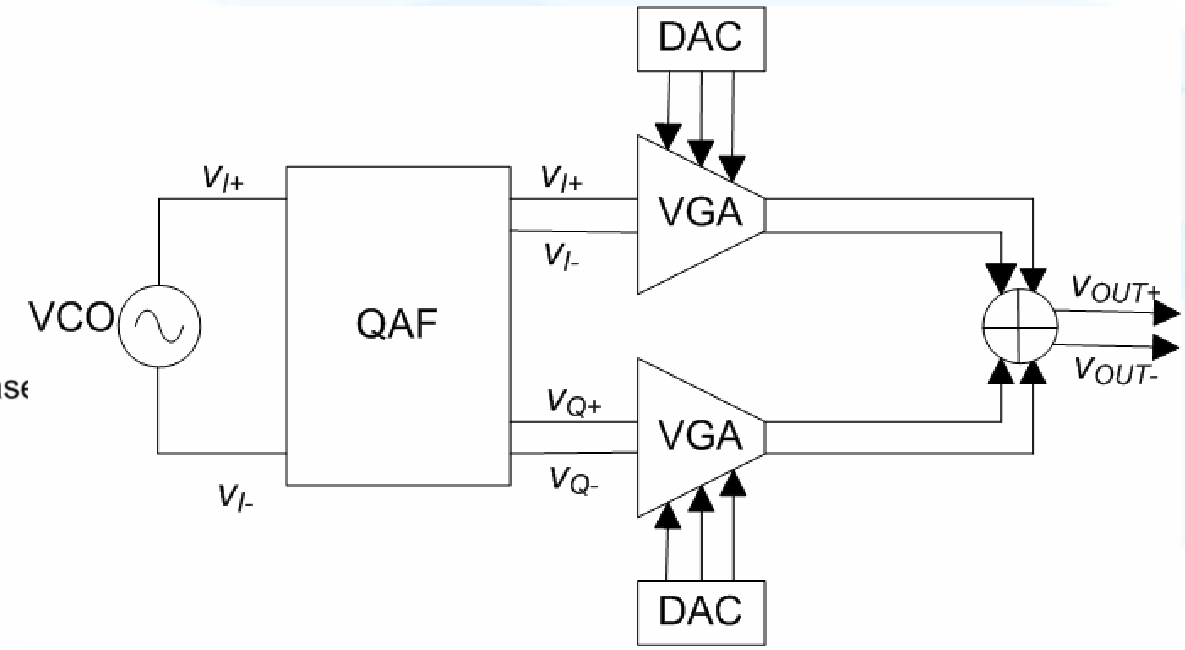
- Vector sum phase shifting method
  - Practically demonstrated at 5 GHz [1]

$$\varphi = \tan^{-1}\frac{V_Q}{V_I}$$

$$V_{RES} = \sqrt{V_I^{\,2} + V_Q^{\,2}}$$



Vector sum method



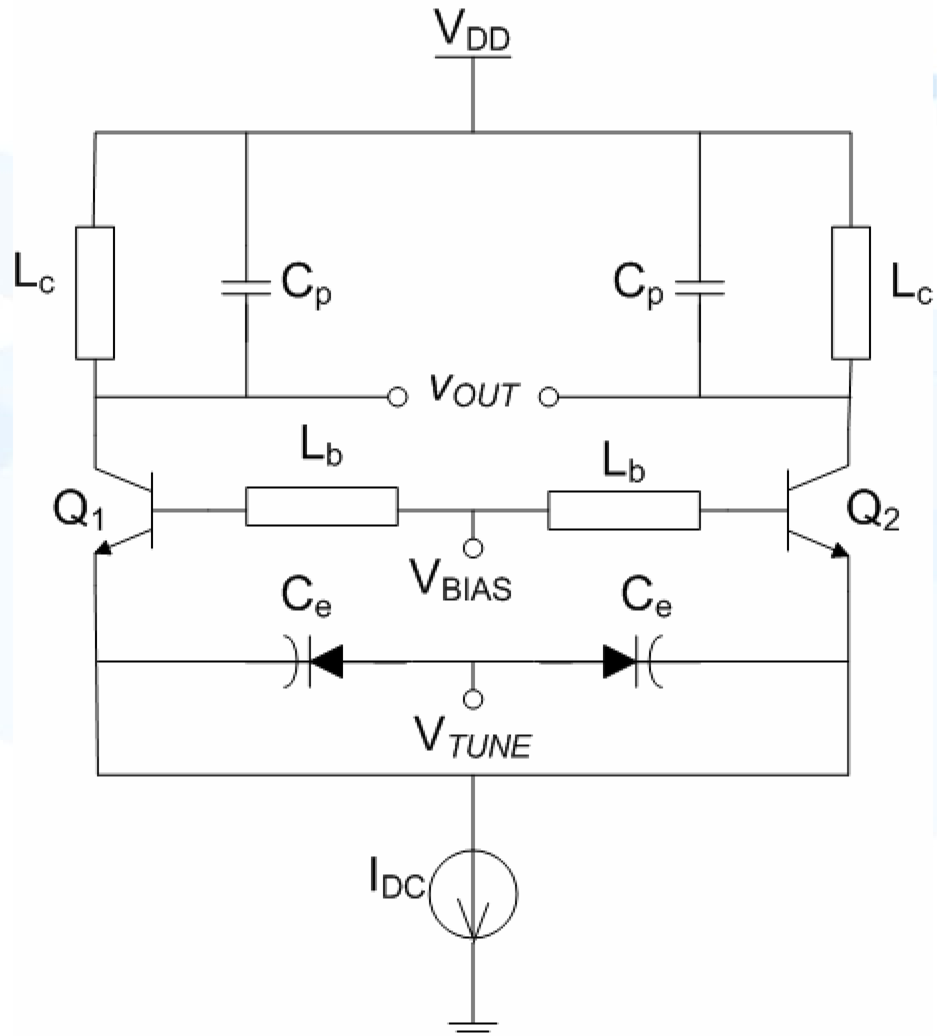
Block diagram

VCO

- Centre frequency of 60 GHz and a tuning range to accommodate process, voltage and temperature variations
- Figure of merit $$\mathrm{FOM} = -L(f_c, \Delta f) + 10.\log\left(\left(\frac{f_c}{\Delta f}\right)^2 \frac{1\mathrm{mW}}{P_{DC}}\right)$$
- Phase noise $$L(\Delta\omega) = 10.\log\left[\frac{P_{sideband}(\omega_0 + \Delta\omega, 1\mathrm{Hz})}{P_{carrier}}\right]$$
- Phase noise improvement
  - Circuit techniques
    - LC oscillators – lowest phase noise
    - Fully differential configuration
    - LC filtering technique
  - Device technology

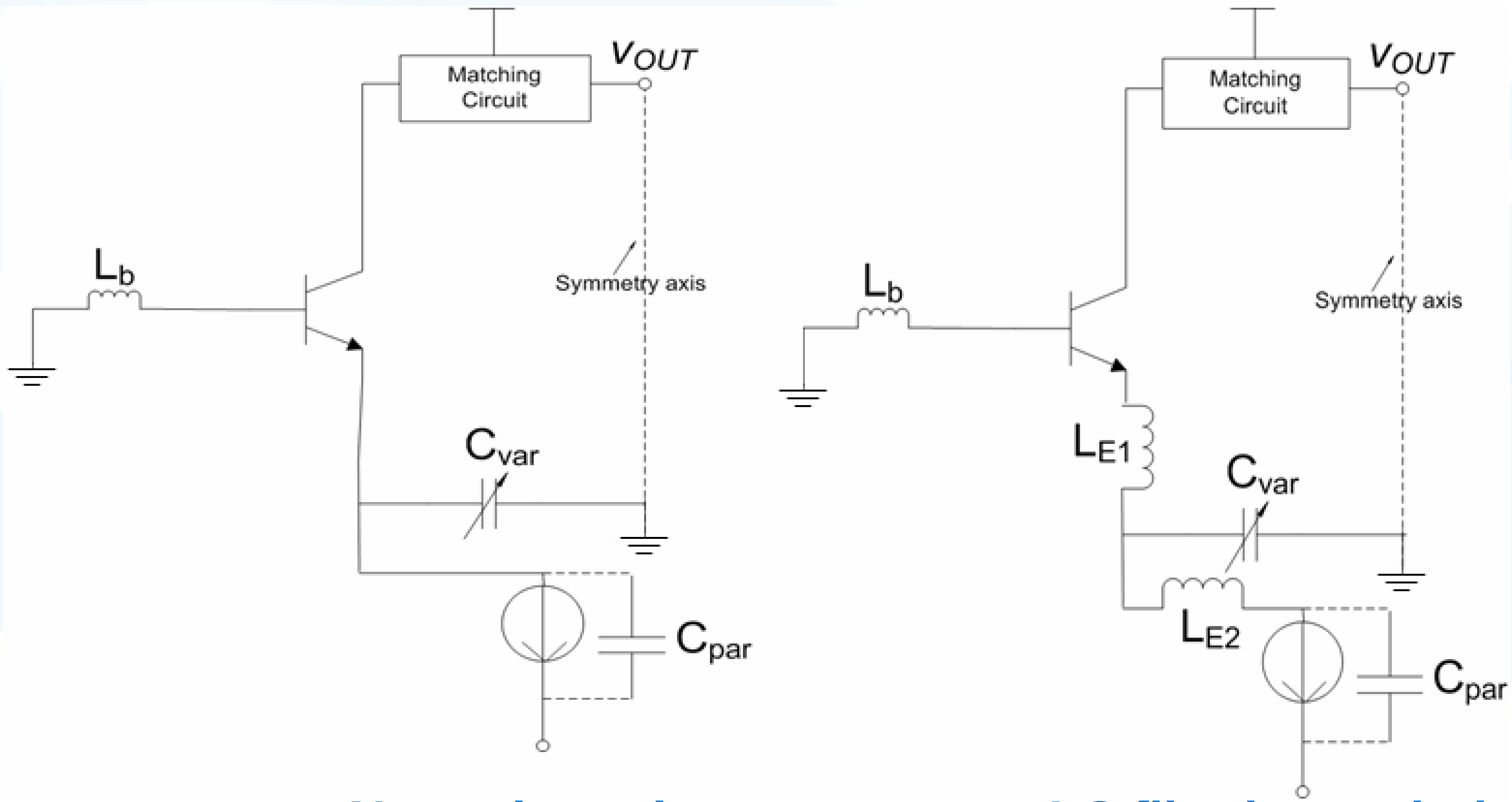
VCO – Basic topology

- Q_{tank} dependant on $Q_{varactor}$
  - MOS varactors are preferred
  - Accumulation mode varactors
- Transmission lines as L



Improving the phase noise

•LC filtering technique – improves phase noise and tuning range [2]

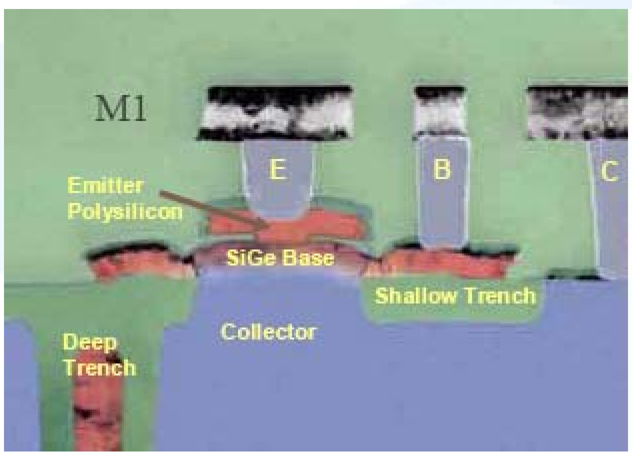


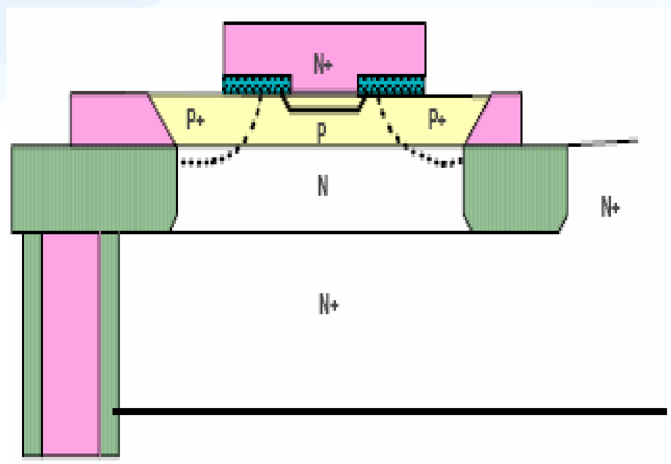
Normal topology LC filtering technique

SiGe BiCMOS technology

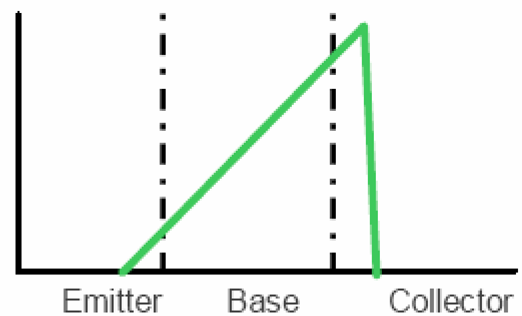
- Low 1/*f* noise
- Graded Ge content in base
  - Reduces base transmit time, τ_b
  - Increases unity gain frequency, f_t

$$\frac{1}{2\pi f_t} \sim \frac{kT}{qI_C}\left(C_{Je}+C_{Jc}\right)+\tau_b+\tau_e+\tau_c+\left(R_e+R_c\right)C_{Jc}+R_{ns}C_{SUB}$$





IBM SiGe structure



Ge content in base

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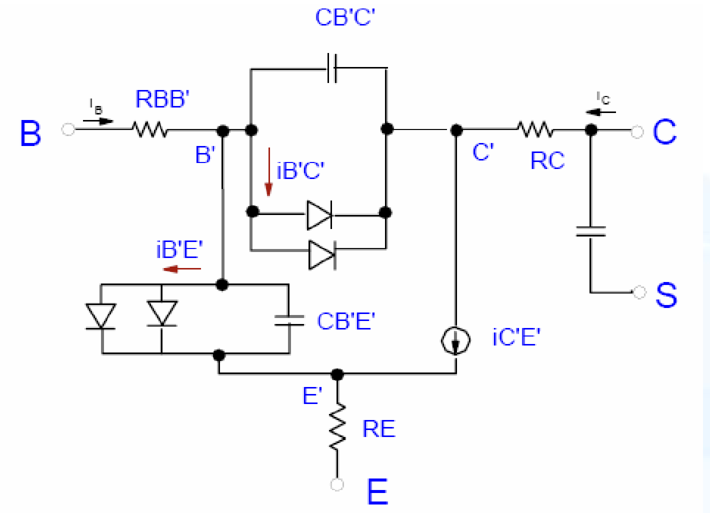
Need for transistor models

- SGPM inaccurate for SiGe transistors at high frequencies
  - Charge storage effects
  - Internal base resistance
  - Self-heating
  - Base-Collector avalanche effect

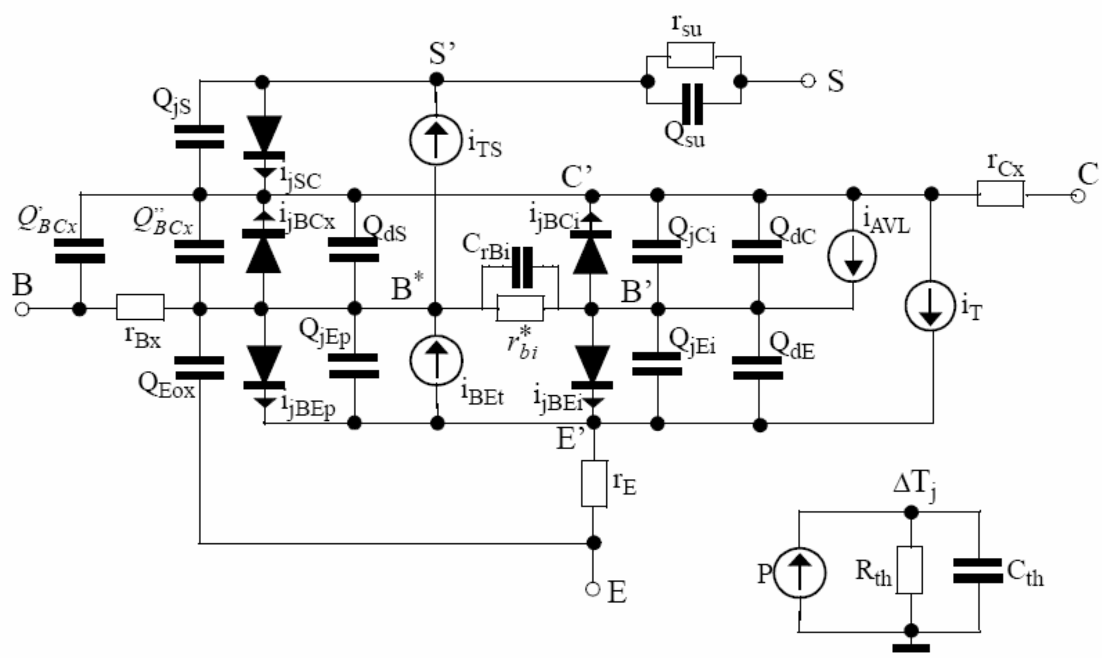


SGPM equivalent circuit

- Advanced models (MEXTRAM, VBIC, HICUM/L2)
  - Complicated – EC, model equations, parameter extraction and computational effort

Parameters for VCO design

- Distributed character of BC capacitance and base resistance
- Operation in low breakdown voltage of SiGe requires BC avalanche effect



Equivalent Circuit of HICUM/L2 [4]

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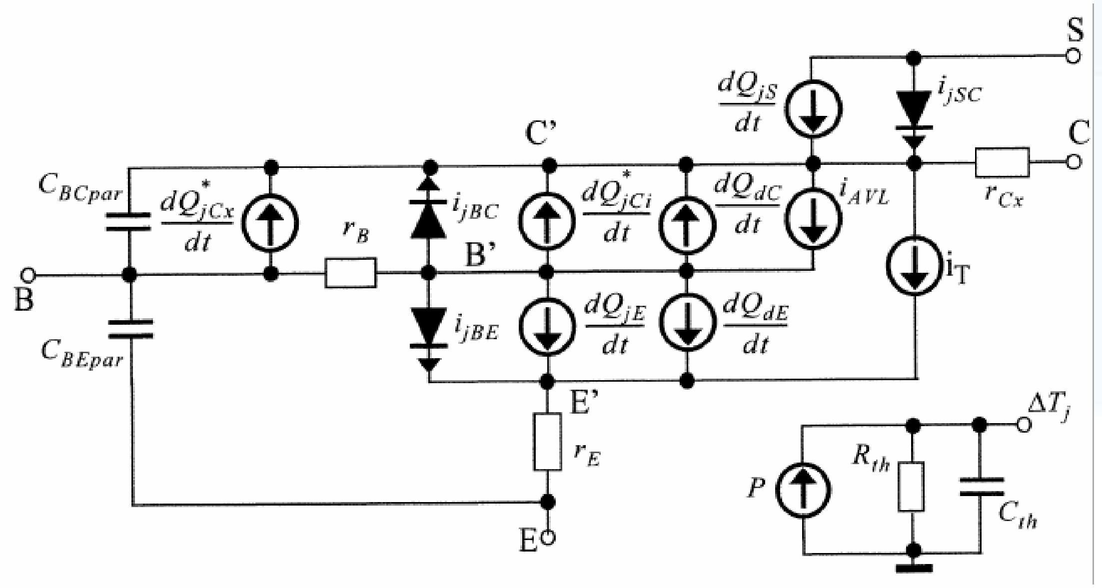
HICUM/L0

- Combines simplicity of SGPM and several important features of HICUM/L2 [3]
- Physics-based and accurate than SGPM
- i_{AVL} : BC Avalanche effect
- $C_{BE_{par}}, C_{BC_{par}}$: Parasitics due to fringing fields in isolation regions
- Self heating network



Equivalent Circuit of HICUM/L0 [5]

HICUM/L0 - Features

•Decoupling of DC and AC behaviour

Parameter extraction easier

•Accurate modelling of τ_b

•DC characteristics – transfer current includes weighted charge components for HBTs

•Bias dependant base resistance, r_B

•Self-heating

Advantages of HICUM/L0

- Circuit design oriented

- Computationally efficient and fast

- HICUM/L0 does not include
  - BE tunnelling current
  - Substrate coupling network
  - Parasitic substrate transistor
  - Capacitance for modelling AC emitter current crowding

Conclusion

•LC filtering technique to improve the phase noise of the VCO

•Investigate the current scaled DACs effectiveness to compensate for the amplitude mismatch introduced by QAF

•HICUM/L0 should be incorporated to improve accuracy of the simulation results

References

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Feedback/Questions

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