Tu2E-2

A 2.4-GHz MEMS-Based Oscillator with Phase Noise of -138 dBc/Hz at 100 kHz Offset and 226 dBc/Hz FoM

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Outline

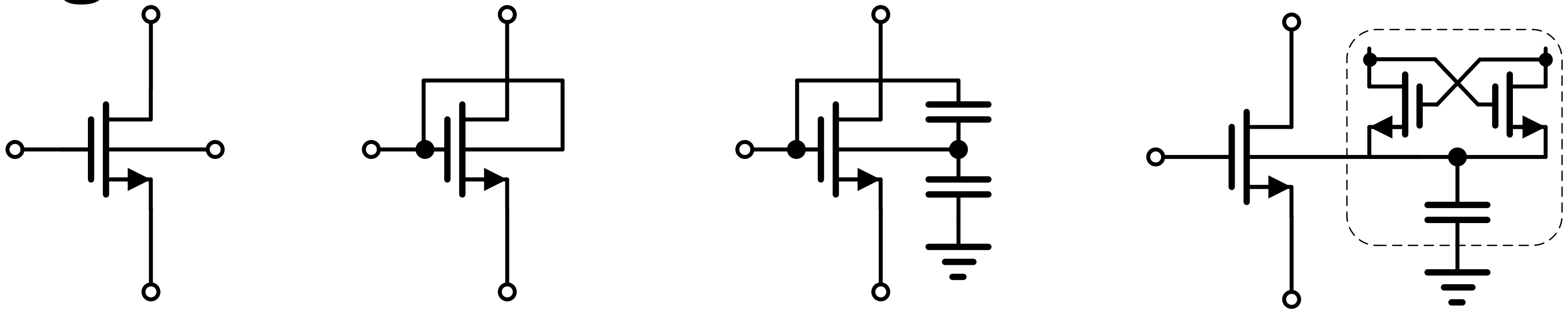
- Motivation
- Proposed MEMS-Based Oscillator
- Circuit Implementation
- Experimental Results
- Conclusion

Motivation

- RF oscillators are one of essential modules
  - Small size, low phase noise, low power
- Micro-Electro-Mechanical-System (MEMS) oscillators are attractive
  - High Q-factor(＞1000)
    - ✓ Improve phase noise
    - ✘ A longer start-up time
  - Integration potential, low cost
- Shorten start-up time helps to save power

Motivation

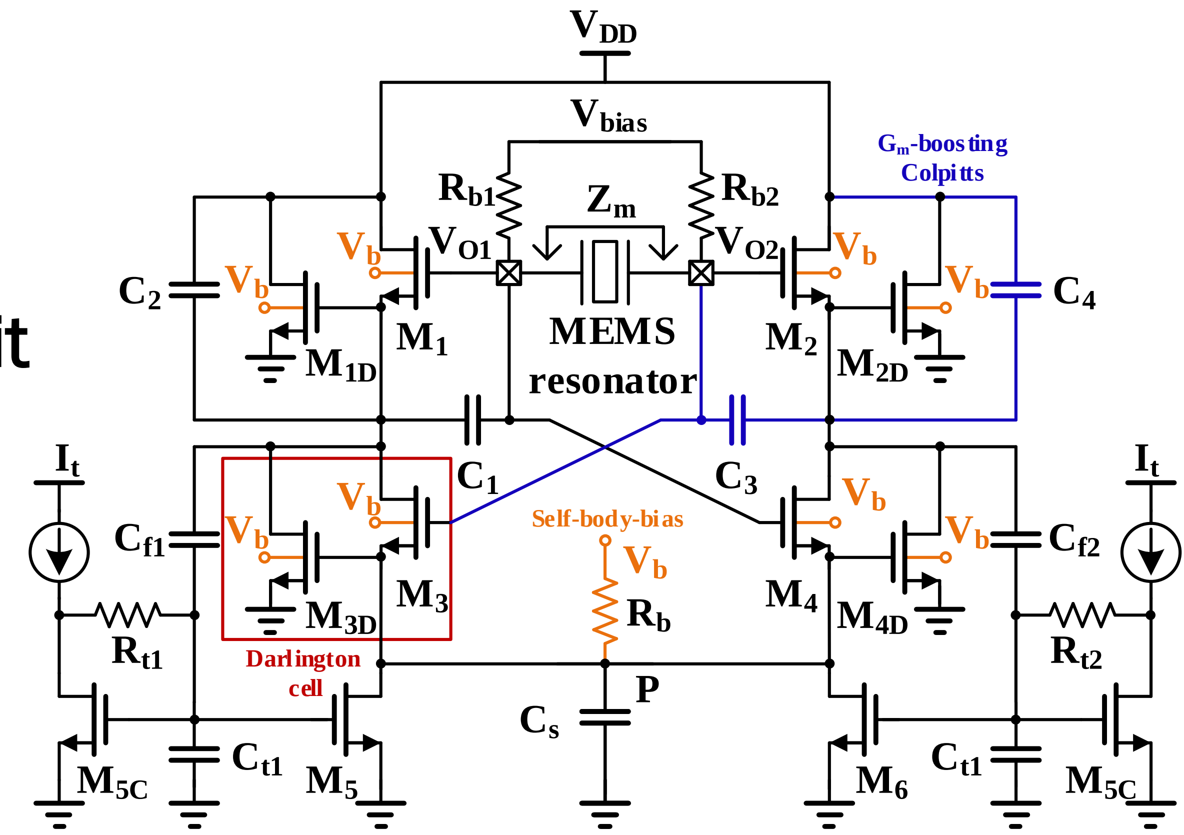
- G_m-boosting techniques are used to shorten start-up time and decrease power
  - – Darlington cell
  - – Body biasing
- Body biasing scheme



<Traditional> <Gate-feedback[7]> <Capacitive-division feedback[8]>
<Amplitude detector-added[10]>

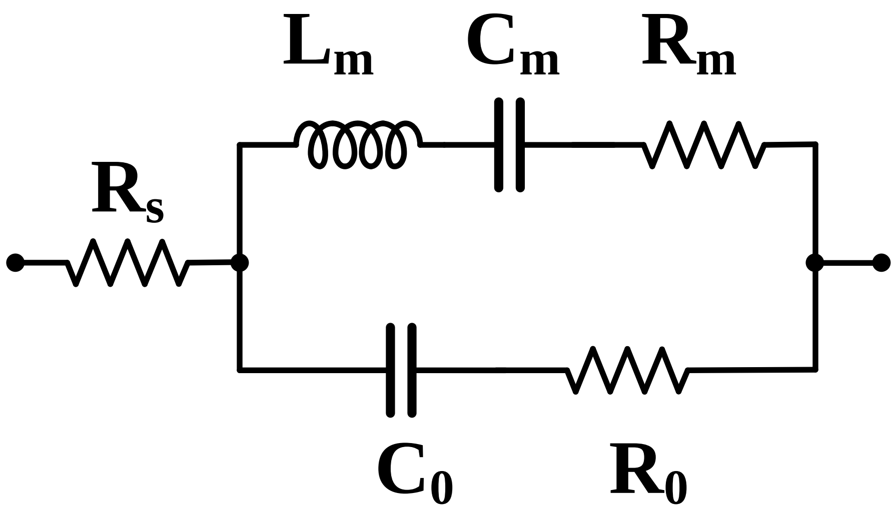
Proposed MEMS-Based Oscillator

- G_m-boosting differential Colpitts
- Dynamic self-body-biasing scheme
- Benefits
  – Senses the voltage from internal circuit to bulk terminal
  – Limitation on output swing is relaxed
  – Deterioration of phase noise caused by large amplitude is decreased

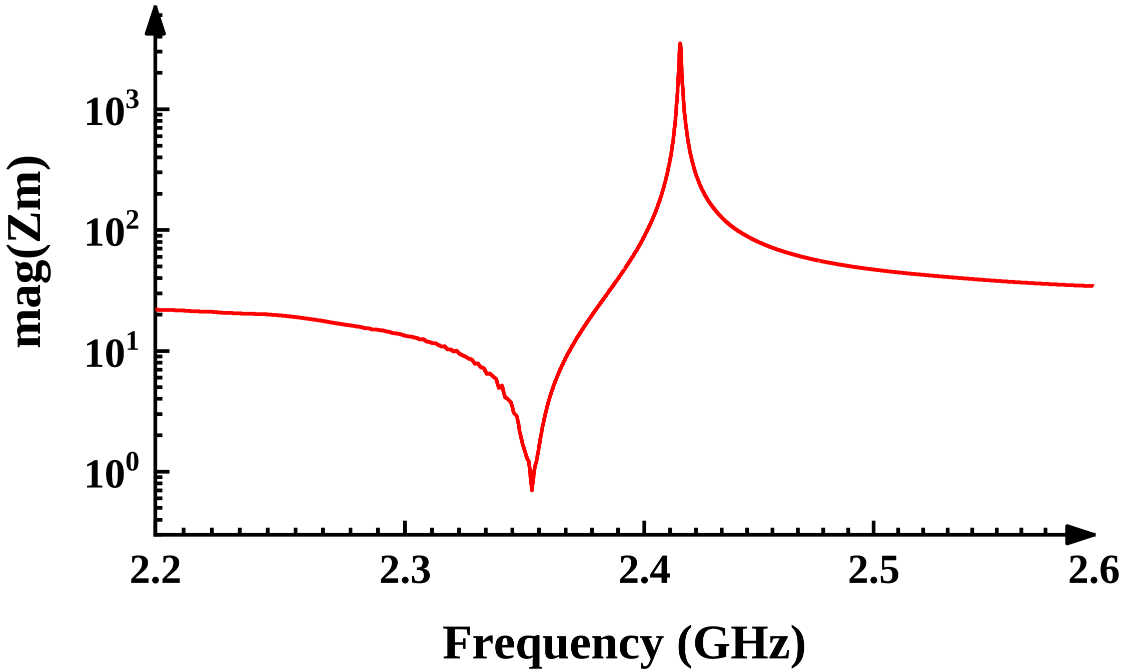


MEMS resonator

- Off-chip MEMS resonator is used for high-Q tank

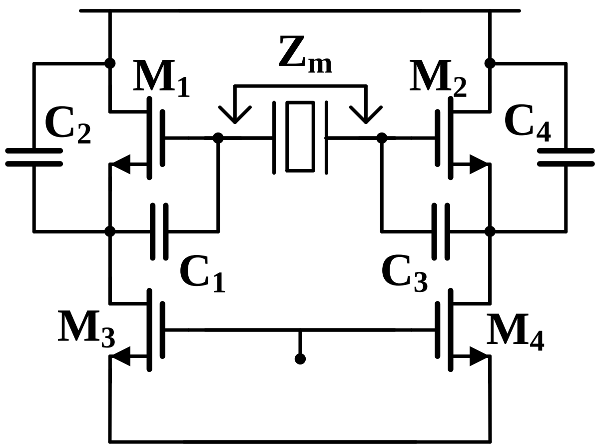


<MBVD model>

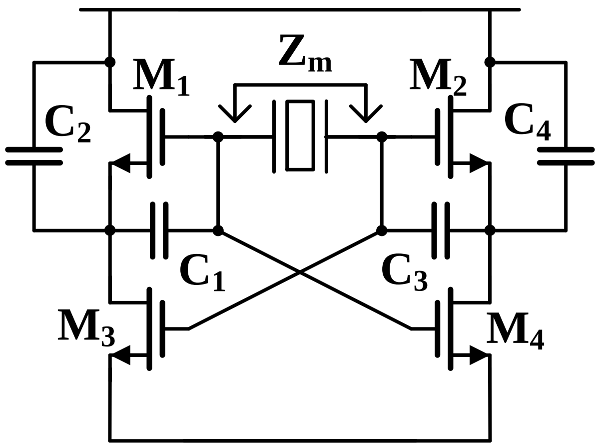


<Impedance response>

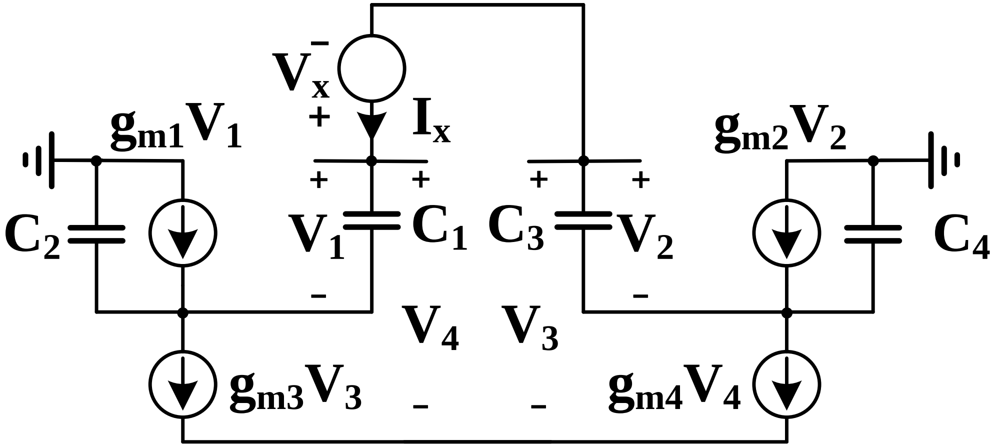
G_m-boosting differential Colpitts



<Conventional differential Colpitts>



<Gm-boosting Colpitts>

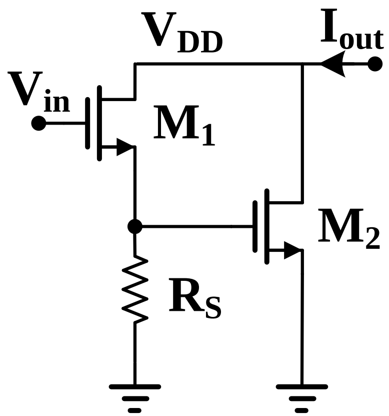


<Small signal model of gm-boosting Colpitts>

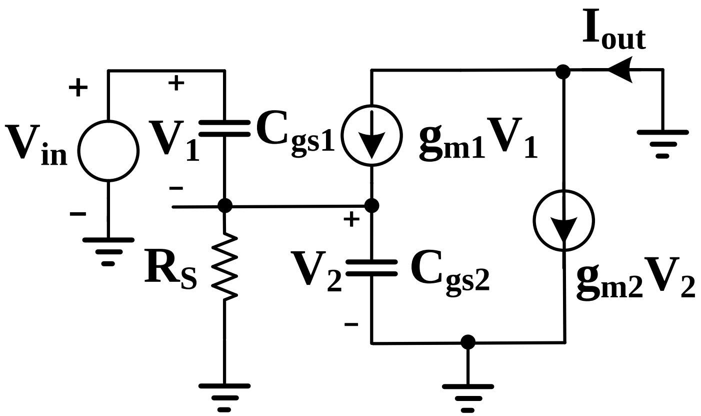
- Assuming that, $g_{m1}=g_{m2}$, $g_{m3}=g_{m4}$
- $$\mathrm{Re}_{G_m}=-\frac{1}{2}\frac{w^2C_1C_2g_{m1}}{g_{m1}^2+w^2(C_1+C_2)^2}\left(1+\frac{g_{m3}}{g_{m1}}\left(1+\frac{C_1}{C_2}\right)\right)$$

G_m-boosting

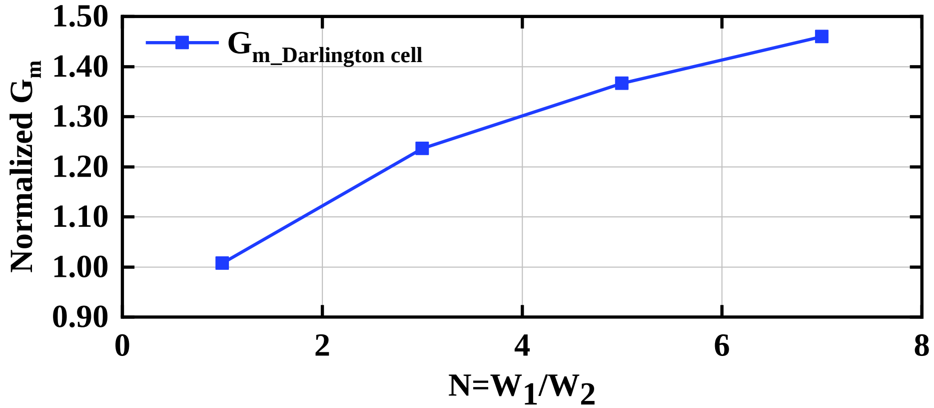
Darlington cell



<Basic Darlington cell structure>



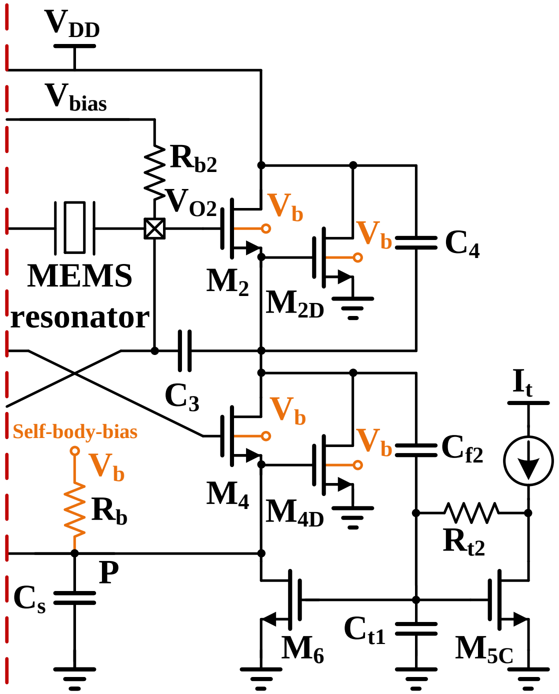
<Small signal equivalent circuit model of Darlington cell>



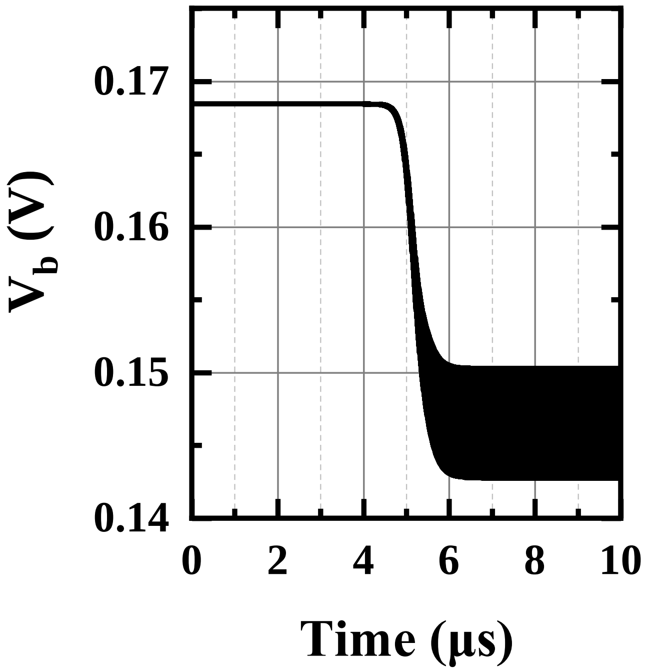
<Normalized transconductance of Darlington cell vary with N>

- $$G_m(D)=\frac{g_{m1}\left(1+g_{m2}R_S\right)+\left(g_{m1}C_{gs2}+g_{m2}C_{gs1}\right)sR_S}{1+g_{m1}R_S+\left(C_{gs1}+C_{gs2}\right)sR_S}$$
- $G_m(D)$ would be optimized by properly selecting the size of M_1 and M_2
- N is the size ratio of M_1 and M_2. Here, N=5

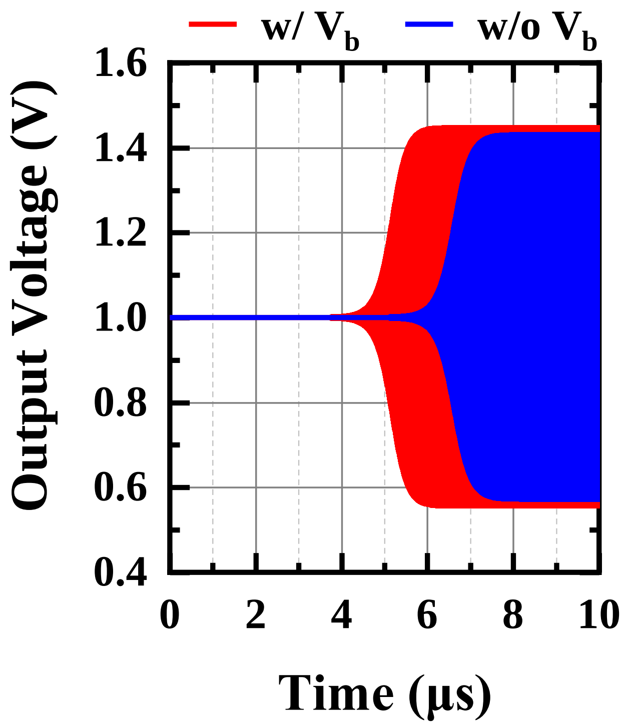
Self-body-biasing



<self-body-biasing>



<Simulation of body bias V_b>

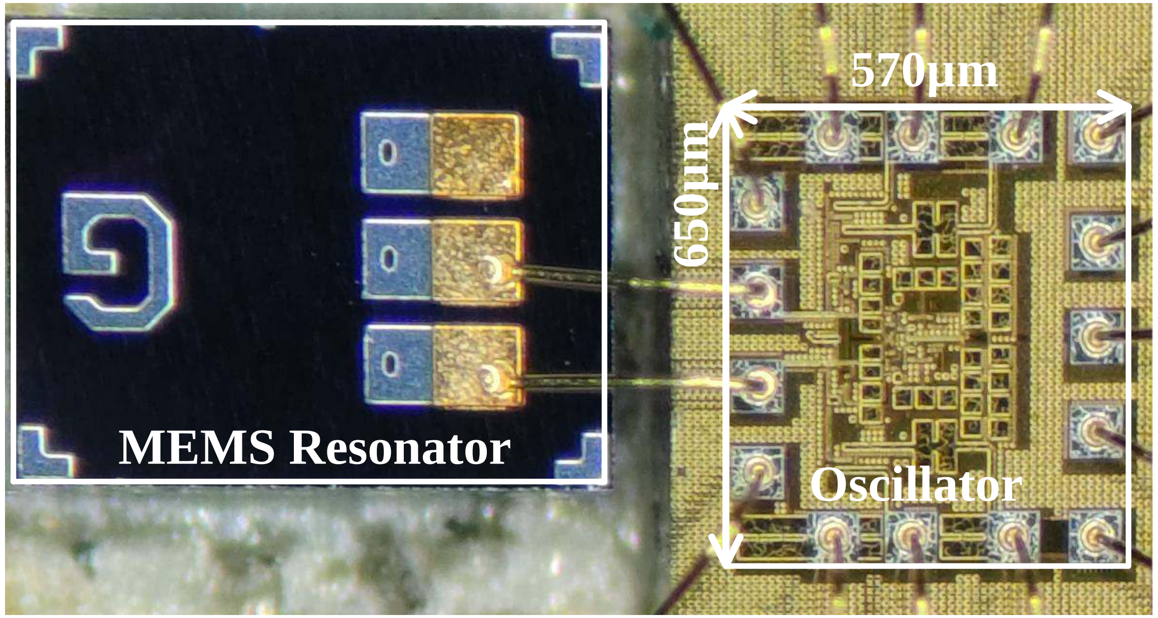


<Simulation of output swing V_{O1}>

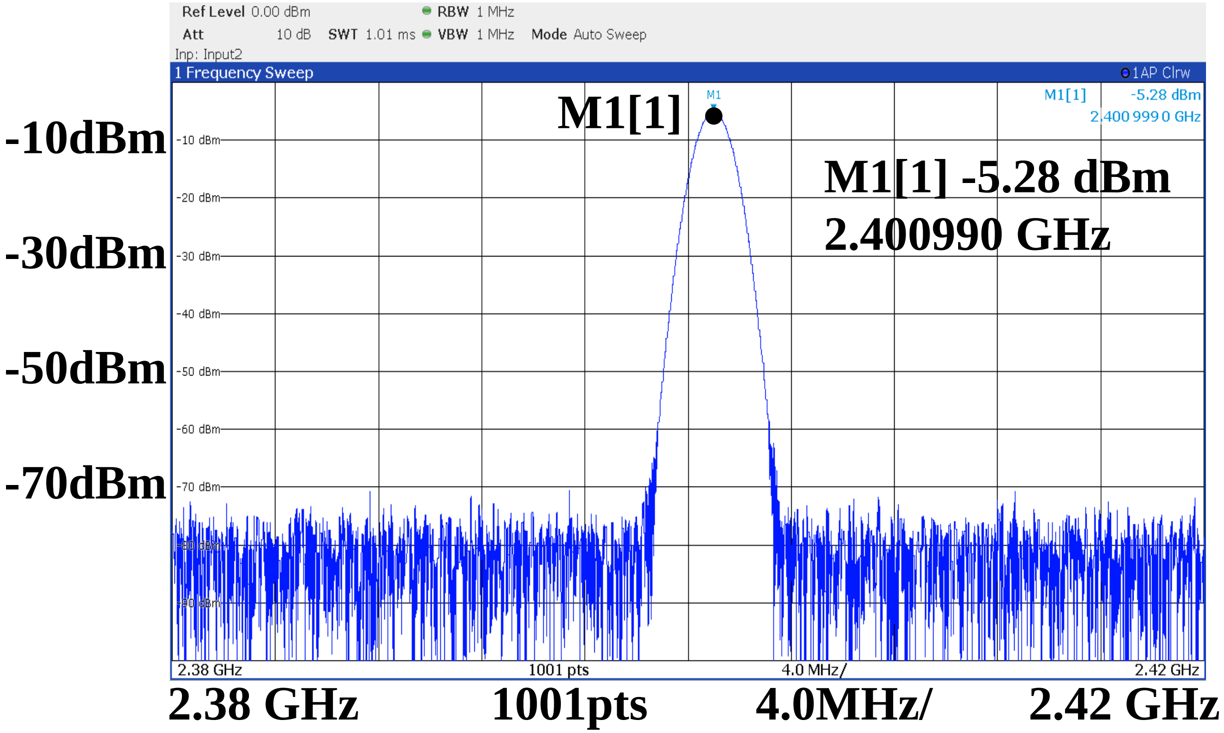
- Dynamic self-body-biasing improves the start-up safety
- Start-up time can be further shorten by adding V_b (red curve) based on the g_m-boosting Colpitts using Darlington cell (blue curve)

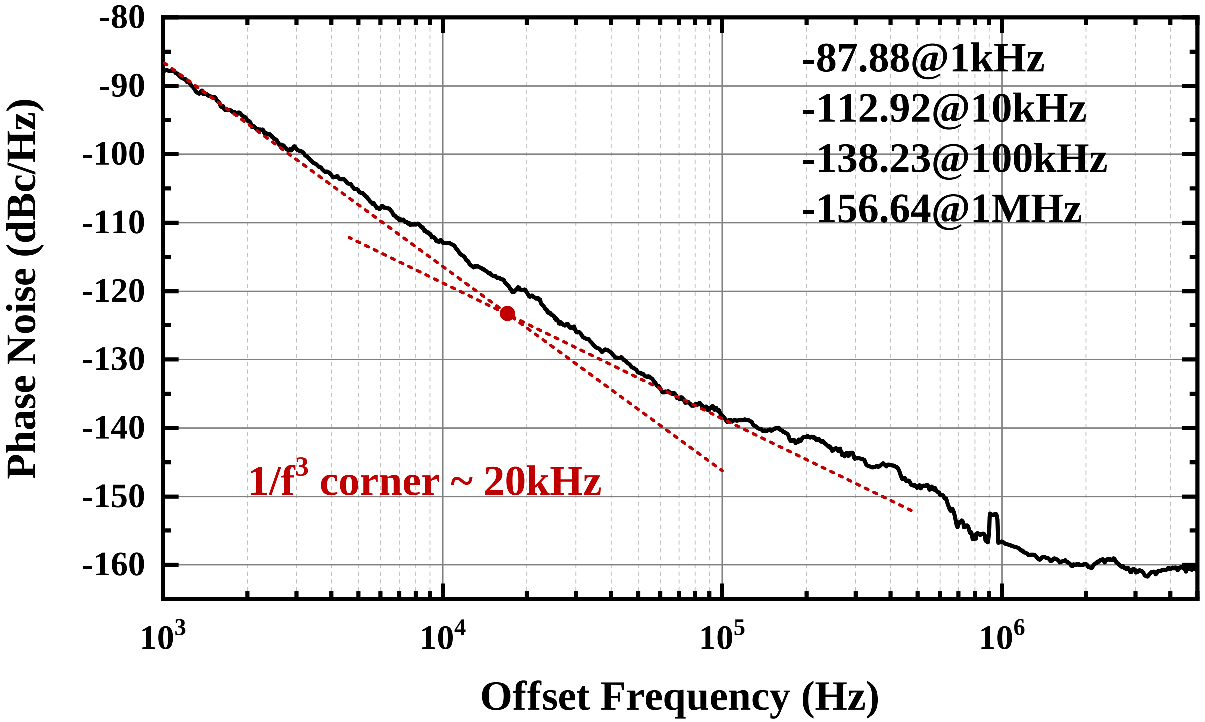
Chip Micrograph

- Fabricated with 180-nm CMOS
- The area of the CMOS chip is 650 μm × 570 μm including pads



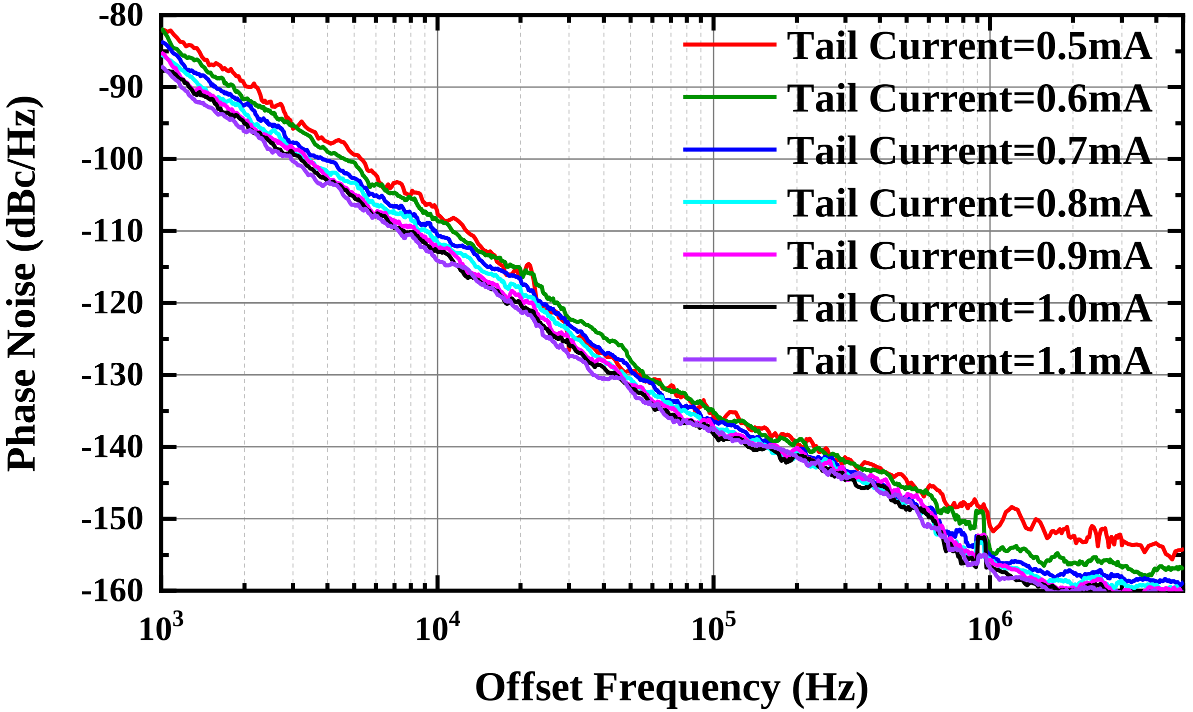
Measured phase noise

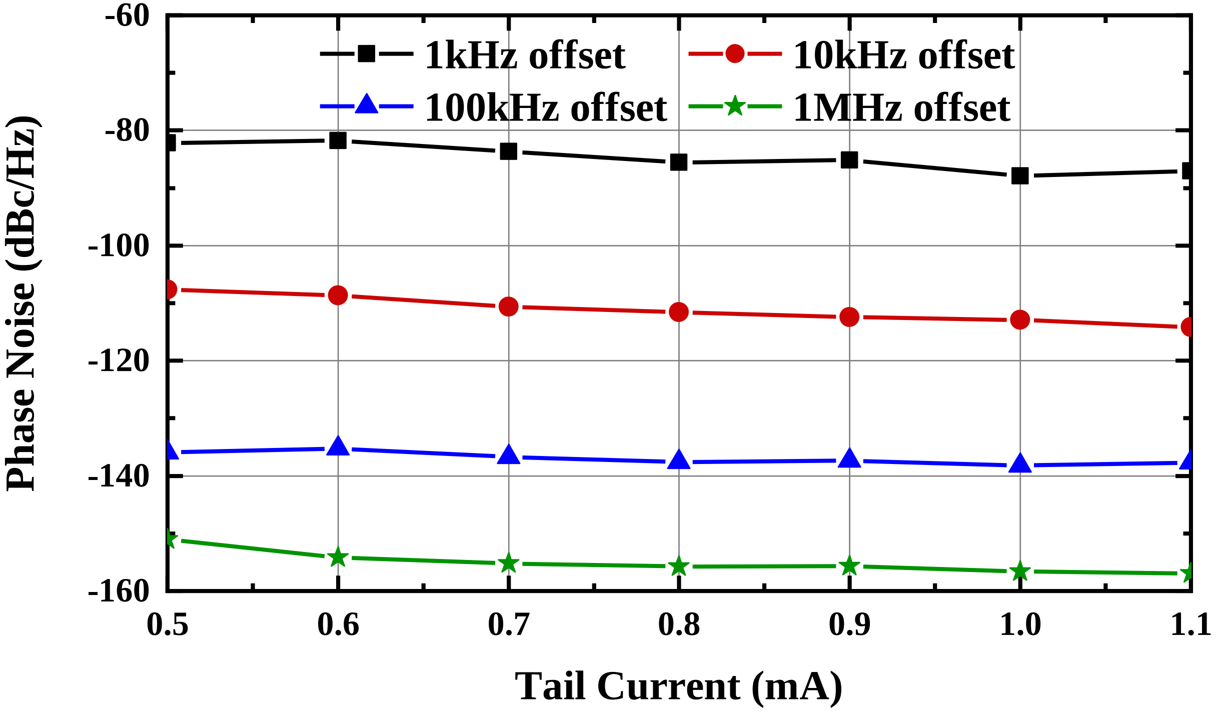




- P_{DC}: 0.98 mW @ 0.7 V supply
- P_{out}: -5.28 dBm at 2.4 GHz
- Phase noise: -138.23 dBc/Hz@100kHz; -156.64 dBc/Hz@1MHz

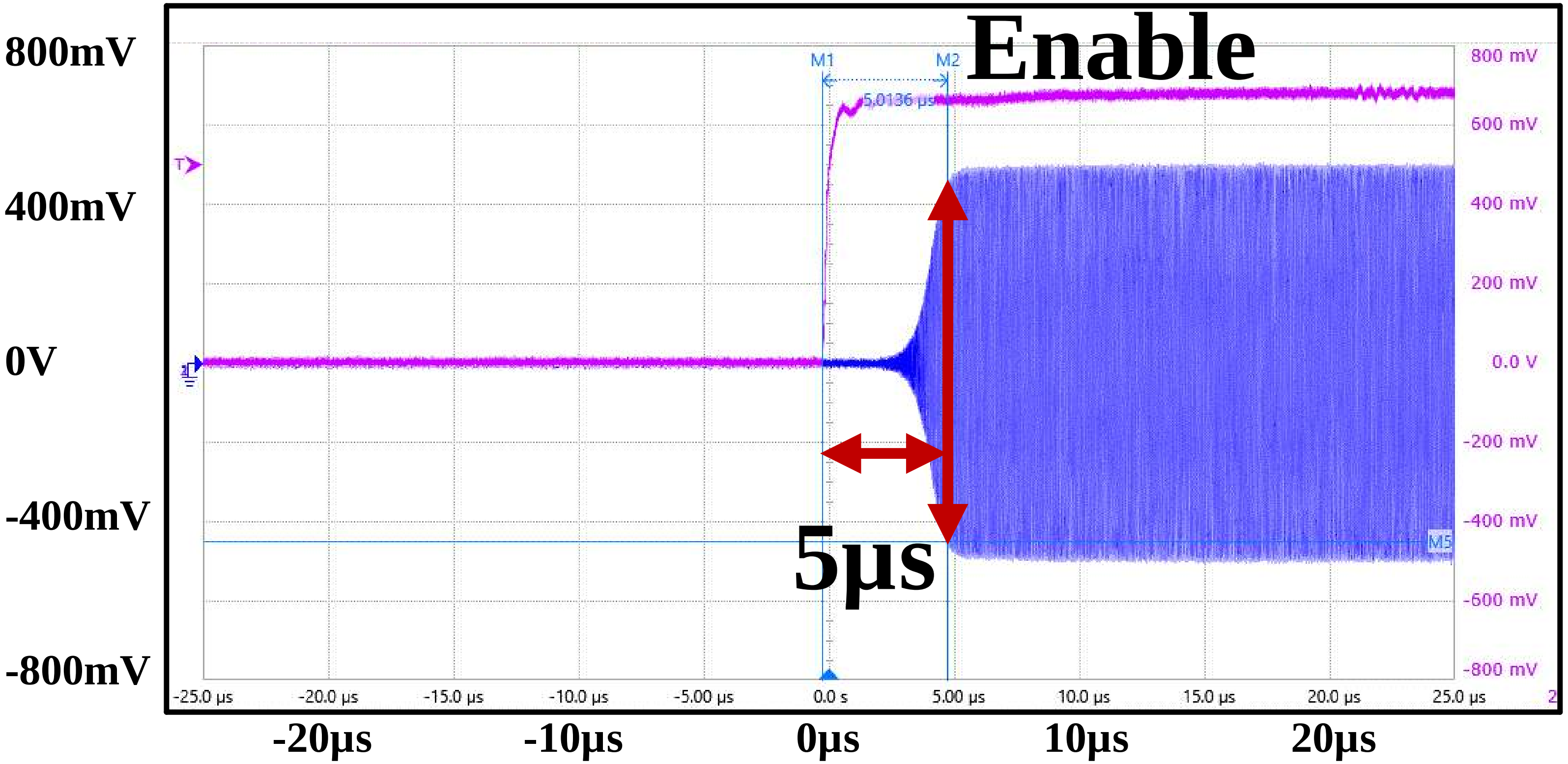
Measured phase noise





- Measured phase noise across tail current from 0.5 to 1.1 mA
- Measured phase noise performance is quite stable

Measured start-up time



- Measured using KEYSIGHT DSOS404A Digital Storage Oscilloscope
- It stabilizes within ~ 5 µs

Performance comparison

Reference	Techn. (nm)	Freq. (GHz)	VDD (V)	PN@1kHz (dBc/Hz)	PN@10kHz (dBc/Hz)	PN@100kHz (dBc/Hz)	PN@1MHz (dBc/Hz)	Start-up time (μs)	PDC (mW)	FoM (dBc/Hz)
[3]CICC'11	130	2	0.6	-68*	-102*	-128	-149	N/A	0.126	224
[11]RFIC'13	130	1.925	1.2	-88.3	-116	-137.2	-146	N/A	1.6	220
[12]EuMIC'14	180	1.984	1.1	-73.23	-100.74	-124.85	-148	N/A	1.7	212
[13]ISSCC'15	65	0.75	0.75	-90*	-115*	-135*	-145	N/A	0.45	216**
[14]TCAS-2'19	65	2	0.6	-68.6	-96.4	-127	-141	N/A	0.35	217
[15]RFIC'21	7	2.492	0.8	-77*	-104*	-128	-140*	N/A	0.416	220
[16]TMTT'15	65	2.46-2.5	1.2	-65*	-96*	-121	-130*	2	1.32	207**
[17]VLSI'19	65	2.4	1.5	-70*	-100*	-120	-127*	<10	>1**	N/A
This work	180	2.4	0.7	-87.88	-112.92	-138.23	-156.64	5	0.98	226

* Extracted from measurement plot ** Calculated

$$FoM = 20\log\left(\frac{f_0}{\Delta f}\right) - 10\log\left(\frac{P_{DC}}{1mW}\right) - L(\Delta f)$$

Conclusion

- A 2.4-GHz MEMS-based oscillator with g_m-boosting technique was designed
- A novel Darlington cell with a dynamic self-body-biasing scheme was proposed
- It has the features of
  - Short start-up time
  - Low phase noise
  - Excellent FoM

Thank you!