

A 9.3MHz to 5.7 GHz Tunable LC-based VCO Using a Divide-by-N Injection-Locked Frequency Divider

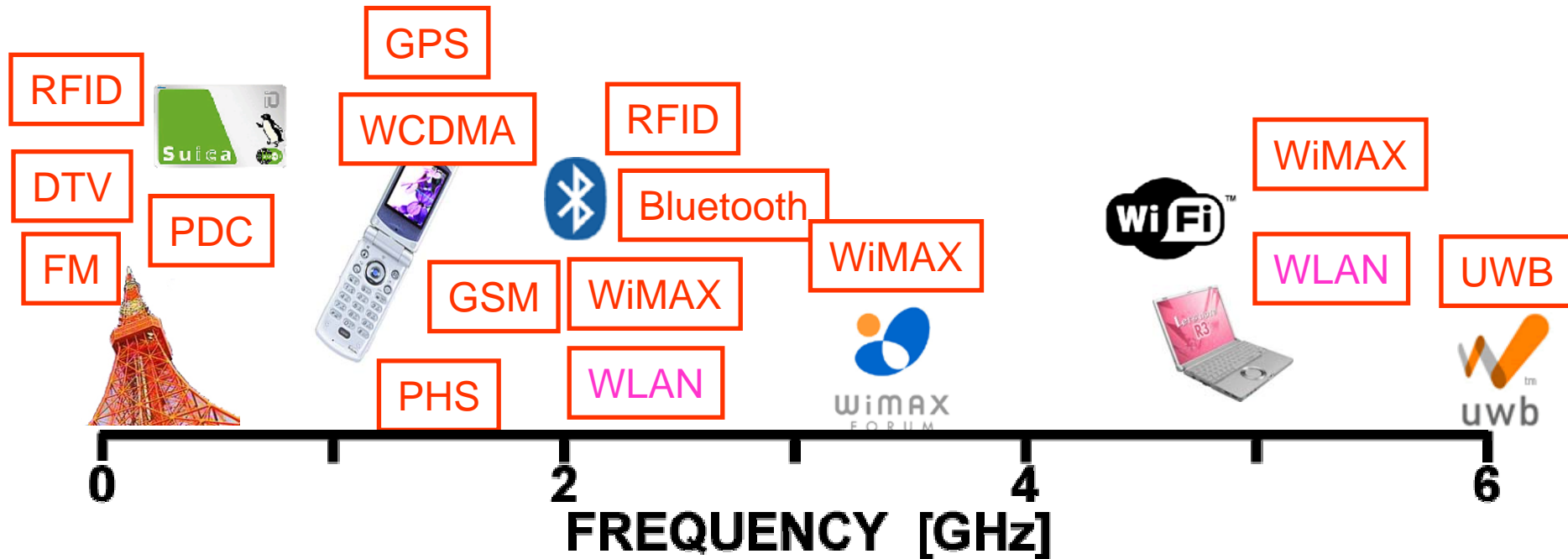
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Outline

- **Background**
- **Wideband VCO using divide by N ILFD**
- **Schematic and Measurement results**
- **Summary**

Background



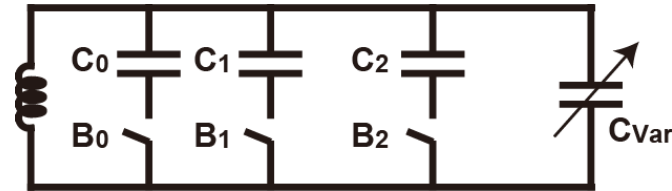
Wideband VCO

- 10 MHz to 6 GHz of frequency range
- Lower phase noise
- Lower power operation
- Smaller size
- Quadrature output
- Spurious tones, *etc.*

Previous work

■ Switched-Capacitor Resonator

- + Reduced K_{vco}
- QL is degraded at edge of tuning range
- Limited C_{max}/C_{min} (parasitic capacitance limited)



■ 1/2 Divider

- + Continuous wide tuning range
- Wide tuning range requirement for VCO
- Poor phase noise

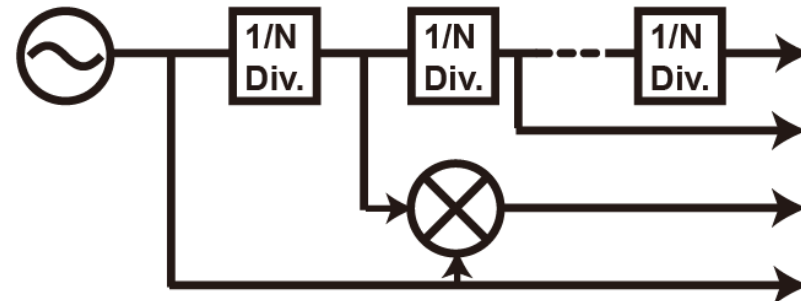
$$\text{Core-VCO : } f_{max}/f_{min} = 2$$



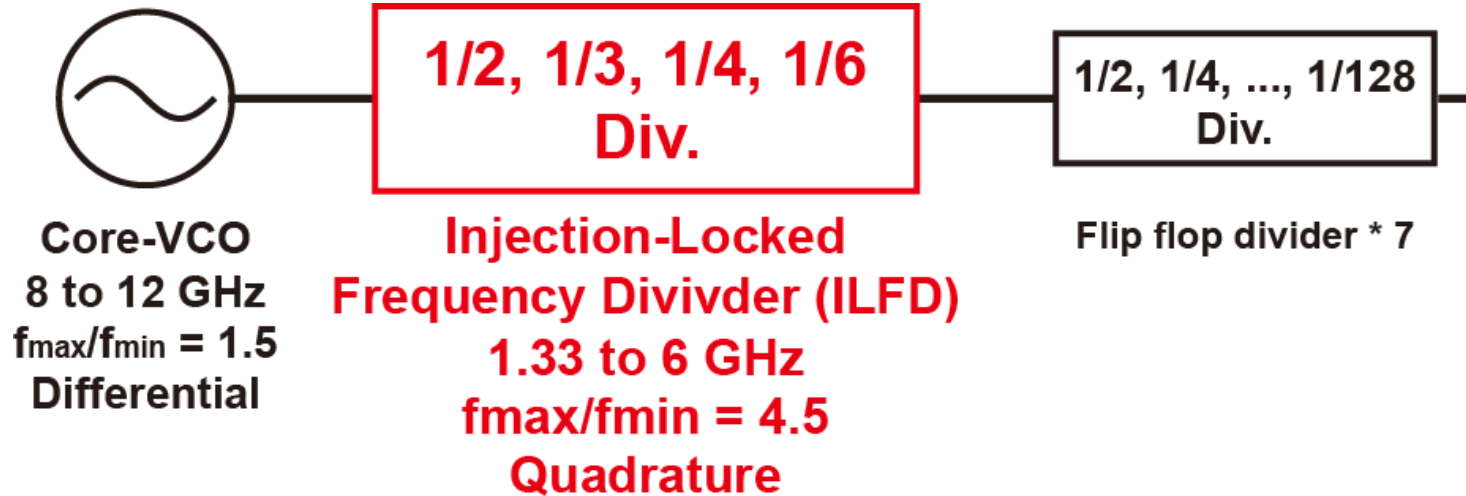
■ Dividers, Mixers

- + Narrow tuning range
- Large power consumption
- Spurious tones

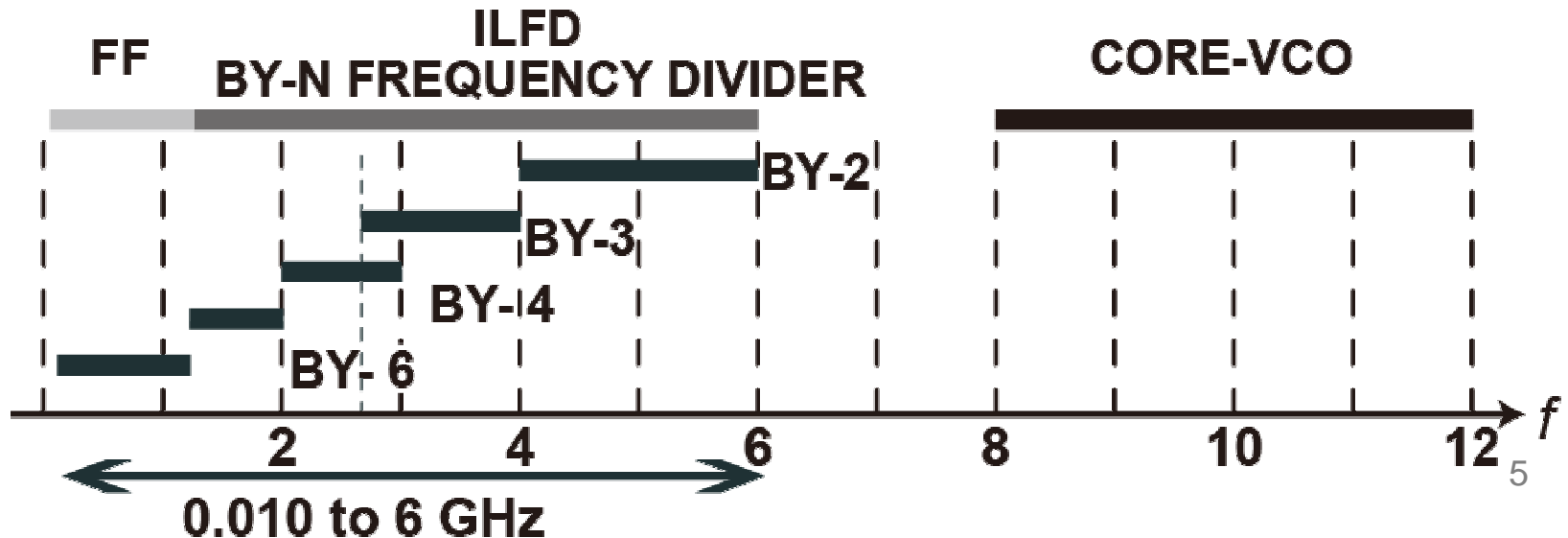
$$\text{Core-VCO : } f_{max}/f_{min} = 1.5$$



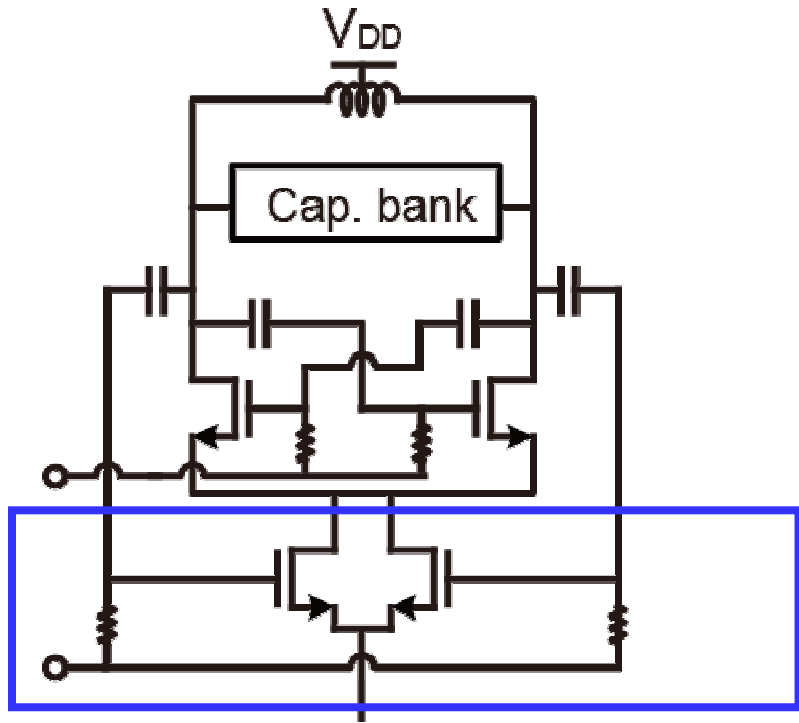
Proposed wideband VCO



Narrow required tuning range, No spur, Quadrature output

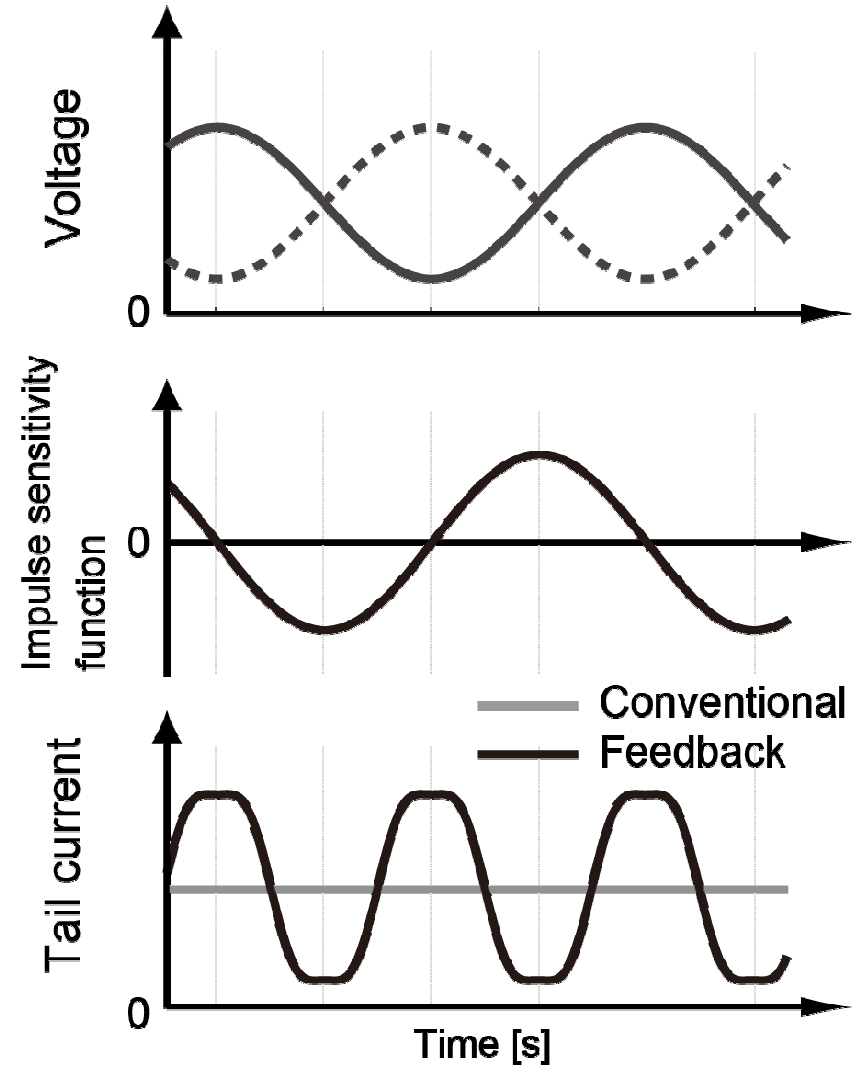


Core VCO

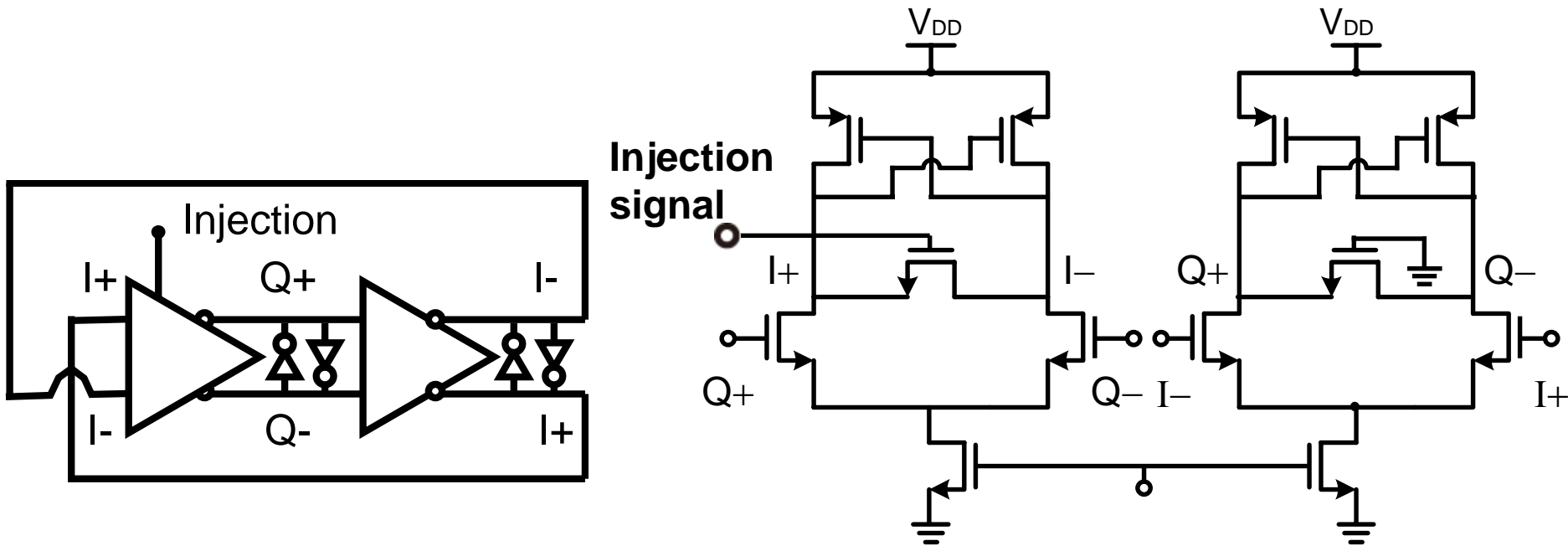


Tail feedback
3.5dB phase noise improvement

- **Tuning range : 8.0 to 12.0 GHz**



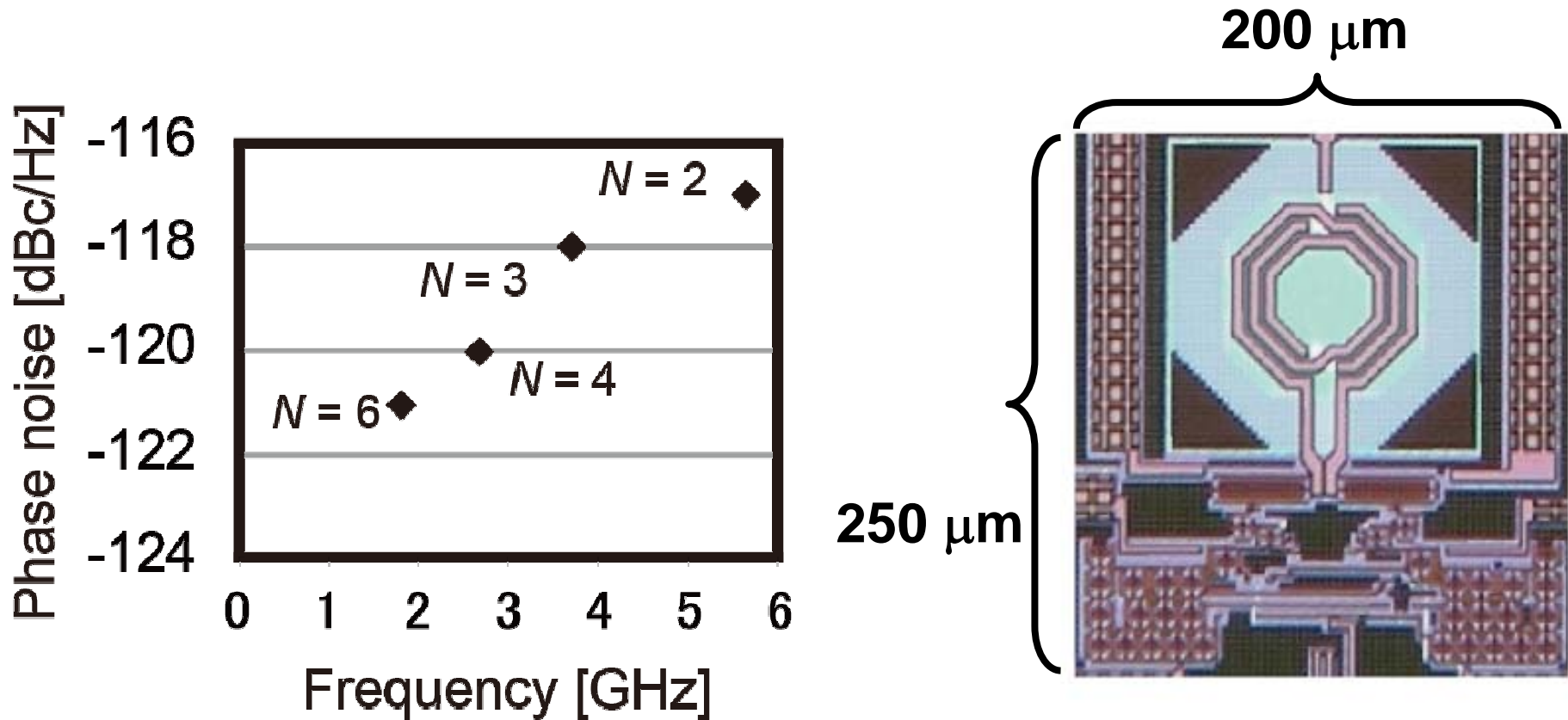
Injection Locked Frequency Divider



- Tuning range : 1.3 to 6.0 GHz
- 2-stage differential ILFD is utilized.

Merit: Quadrature output, No Spur, Wide frequency range

Measurement result



Fabricated by 90 nm CMOS Process

VCO measurement summary

| | This work | VLSI 2009[2] | RFIC 2009[3] |
|-----------------------------|----------------------------|------------------------------|-------------------------|
| Architecture | VCO with ILFD | QVCO with mixer and dividers | 2VCOs and dividers |
| Divide ratio | 2,3,4,6... | 2,3,4,5, 6,8,10 | 2,4,8,16,32... |
| Tuning range of core LC-VCO | ± 20 % | ± 20 % | ± 33.3 % (total) |
| Output freq. | 0.009 - 5.7 GHz | 1 - 10 GHz | 0.1 - 5.0 GHz |
| Power cons. | 5.9 - 11.2 mW | 31 mW | 19.8 mW |
| FoM _T | -210 dBc/Hz | -194 dBc/Hz | -209 dBc/Hz |
| Area | 0.05 mm² | 0.29 mm ² | 0.22 mm ² |

$$FoM_T = L(\Delta f) - 20 \log \left(\frac{f_o}{\Delta f} \cdot \frac{FTR}{10} \right) + 10 \log \left(\frac{P_{VCO}}{1 \text{ mW}} \right)$$

[2] B. Razavi, *VLSI Circuits*, June 2009.

[3] P. Nuzzo, *et al.*, *RFIC*, June 2009.

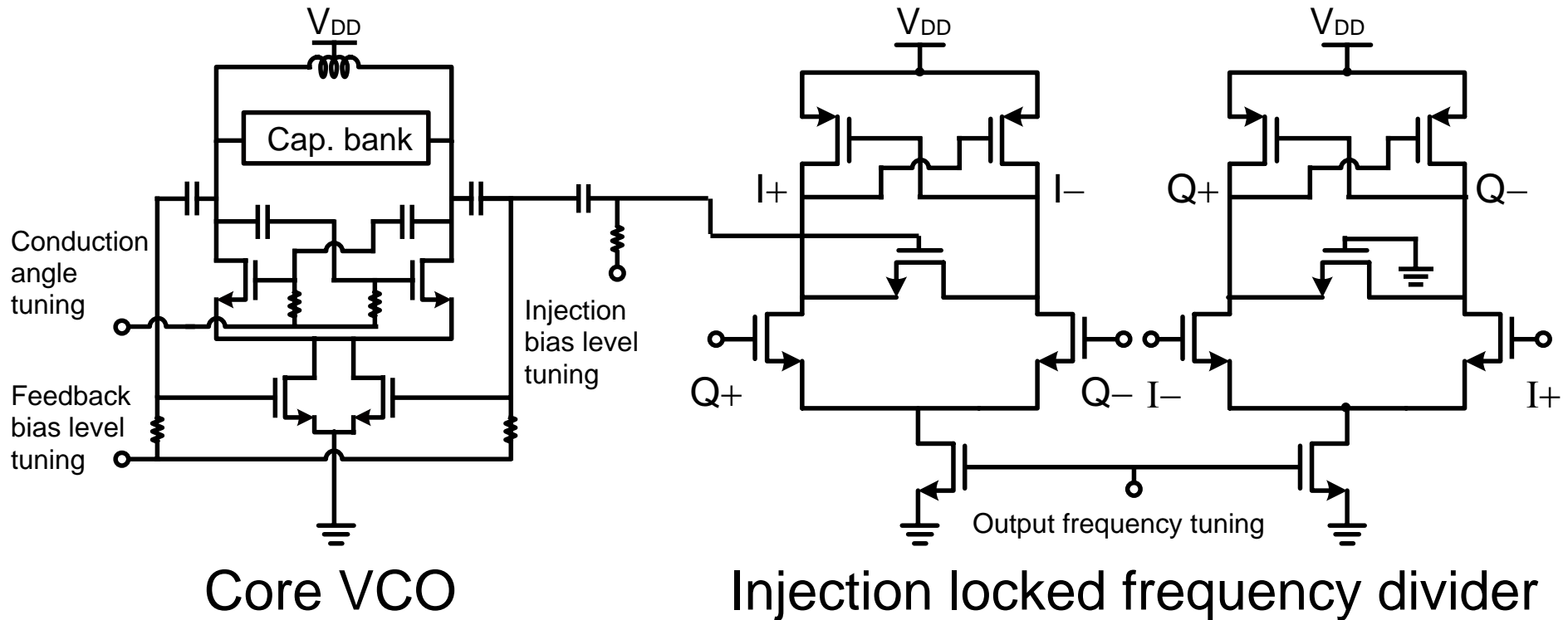
Summary and conclusion

- A differential LC-VCO and injection locked frequency divider are utilized instead of a QVCO and a SSBM for the spurious and narrow band and small area.
- The proposed wideband VCO can achieve wide tuning range with sufficient phase noise.

FTR=199% FOM_T=-210dBc/Hz

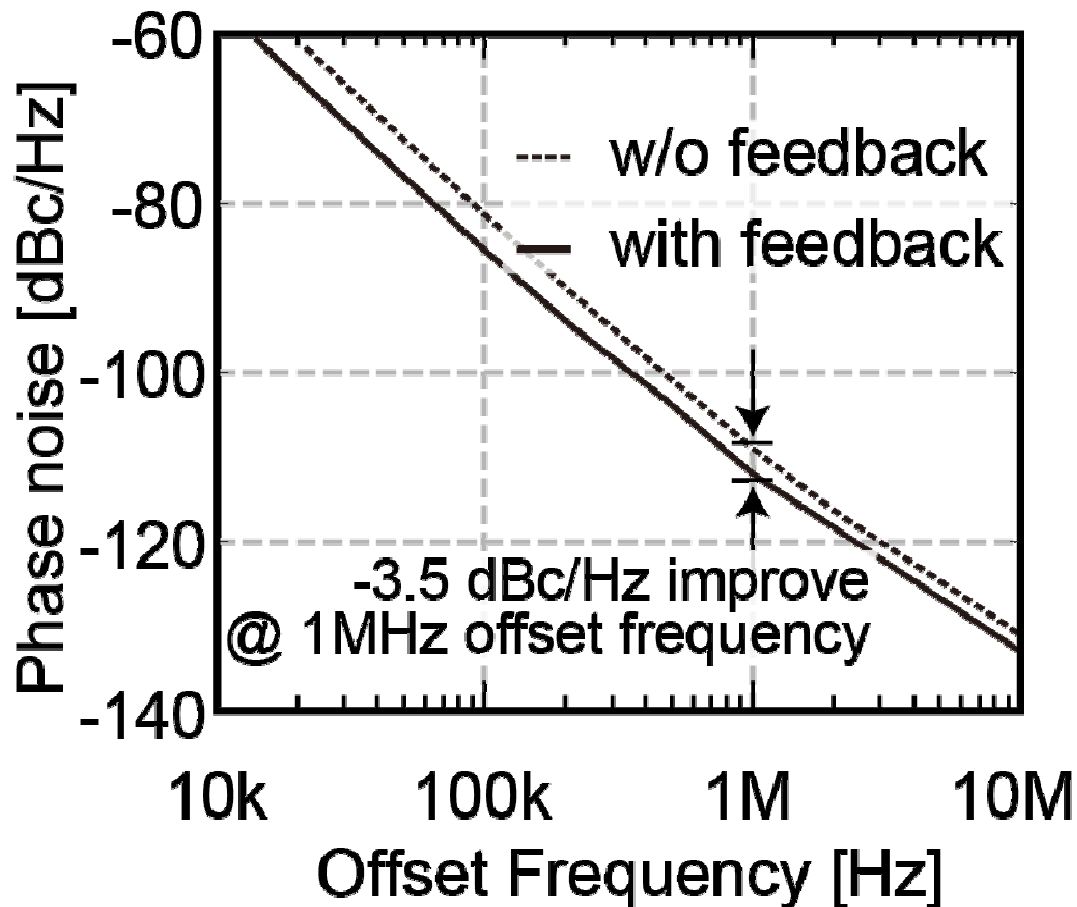
**Thank you
for your attention!**

Circuit schematics



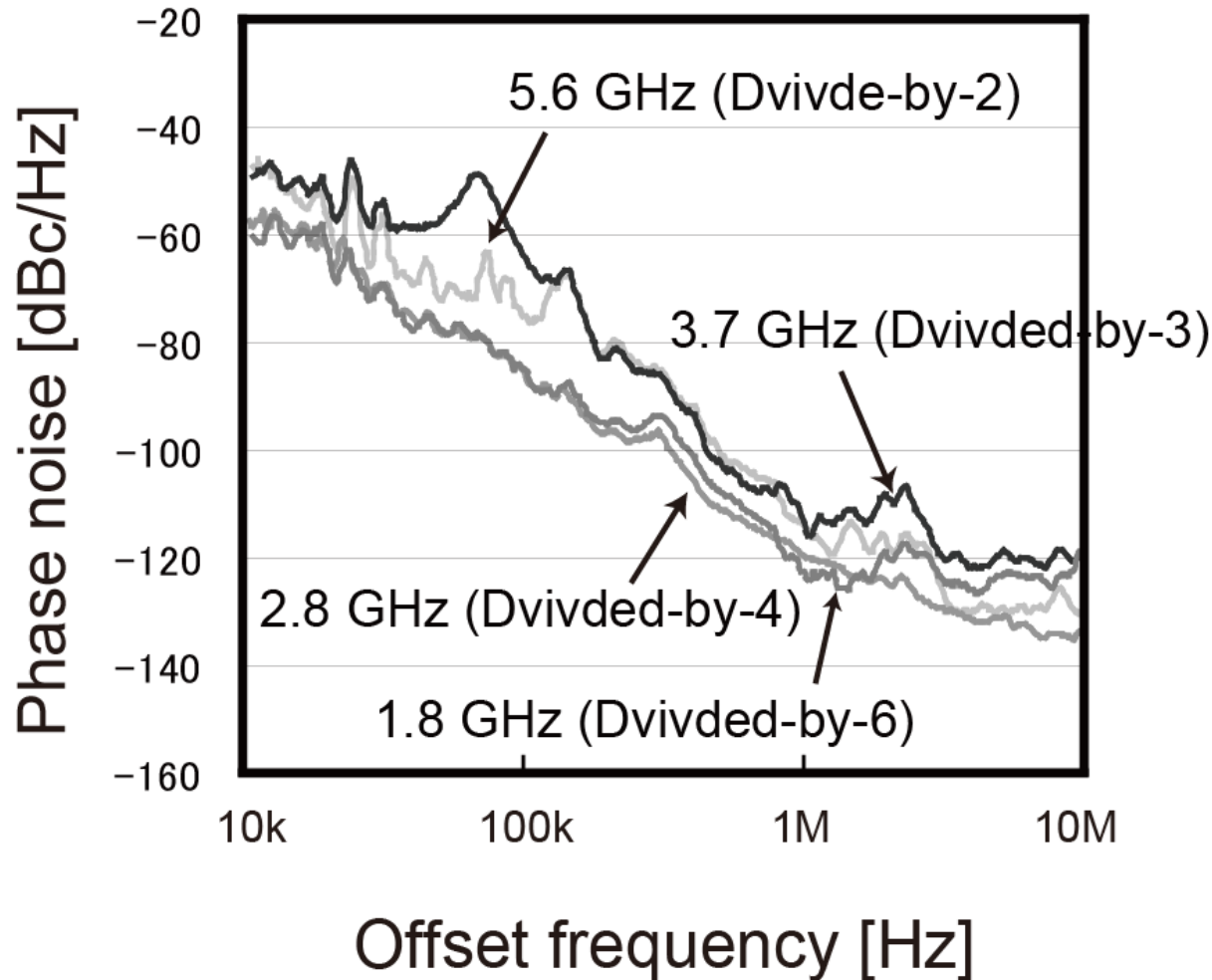
- **ILFD generates 1.33 to 6.0 GHz output.**
- **Lower frequency (under 1.33GHz) can be obtained by using FF dividers.**

Simulation result of feedback VCO



Feedback VCO can improve phase noise with smaller power consumption

Phase noise

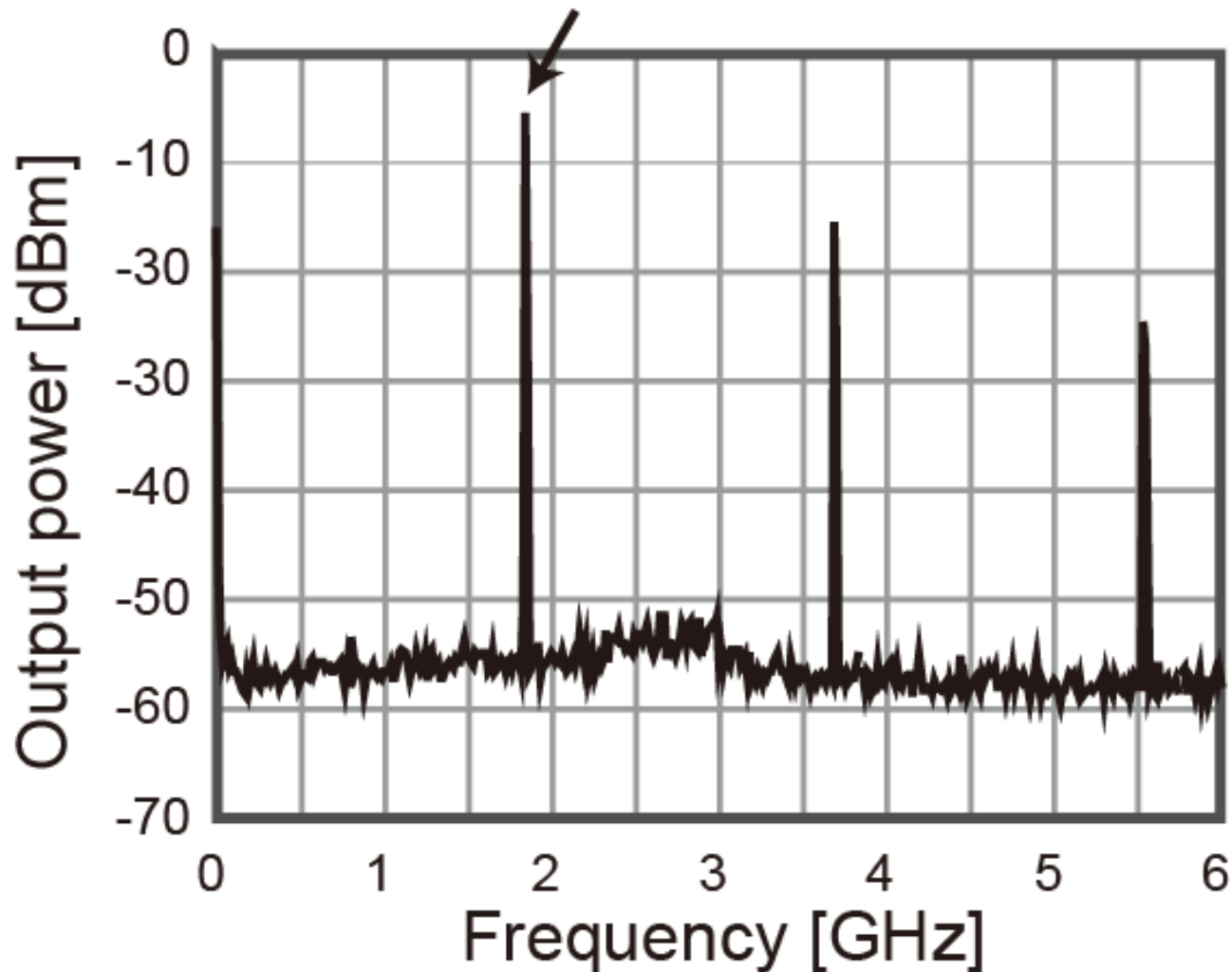


Phase noise 2

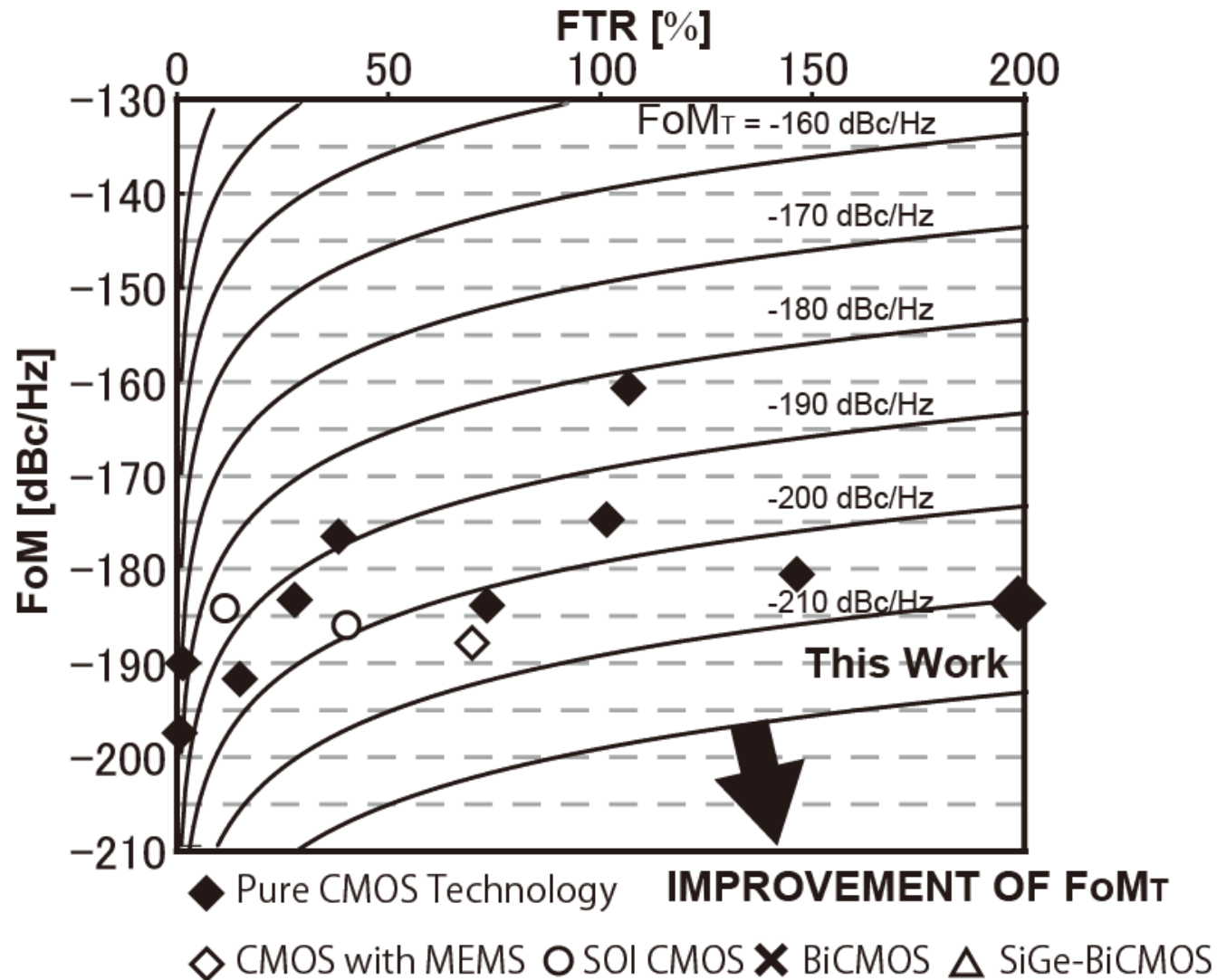
| Oscillation frequency | Phase noise @ 1MHz offset | FoM | FoM _T |
|-----------------------|---------------------------|-------------|------------------|
| 5.6 GHz ($1/2 f_o$) | -117 dBc/Hz | -184 dBc/Hz | -184 dBc/Hz |
| 3.7 GHz ($1/3 f_o$) | -118 dBc/Hz | -184 dBc/Hz | -184 dBc/Hz |
| 2.8 GHz ($1/4 f_o$) | -120 dBc/Hz | -184 dBc/Hz | -184 dBc/Hz |
| 1.9 GHz ($1/6 f_o$) | -121 dBc/Hz | -184 dBc/Hz | -184 dBc/Hz |

Output spectrum

1.87 GHz @ divided-by-6 operation



Performance comparison



VCO performance

| | |
|----------------------------------|---------------------------------------|
| Technology | FUJITSU 90nm CMOS |
| Supply voltage | 1.2 V |
| Power consumption of VCO core | 4.8 - 10.2 mW |
| Power consumption of ILFD | 1.0 - 1.3 mW |
| Power consumption of FF dividers | - 0.1 mW |
| Total power consumption | 5.9 - 11.2 mW |
| Tuning range | 9.3 MHz - 5.7 GHz |
| Chip area | 250 μm x 200 μm |