IDEC Chip Design Contest

Transformer-based Injection Locked Frequency Divider

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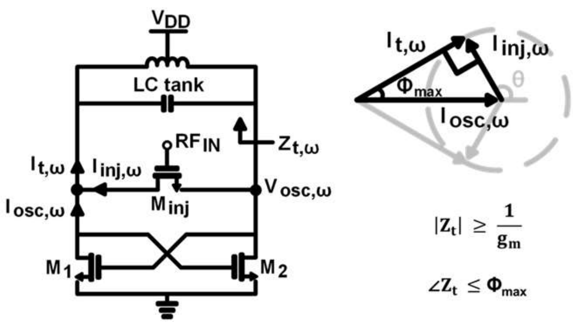
Introduction

- A broadband frequency divider operating at millimeter-wave (mm-wave) is an essential block for 5G FR2 communication system.
- Injection-locked frequency divider (ILFD) can operate at high frequencies with low power consumption.
- However, conventional ILFD typically suffers from the issue of having a narrow locking range.
- Therefore, it is necessary to widen the locking range of the ILFD for 5G communications.

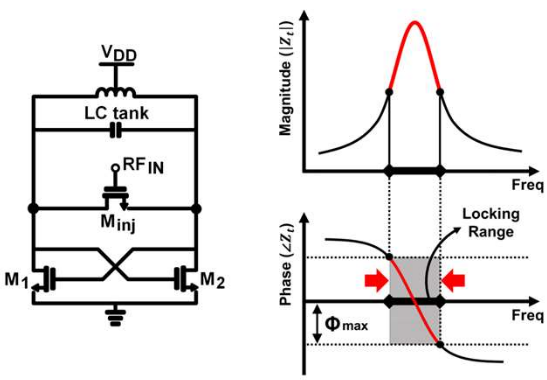
Circuit Design

- **Conventional ILFD and operating condition**



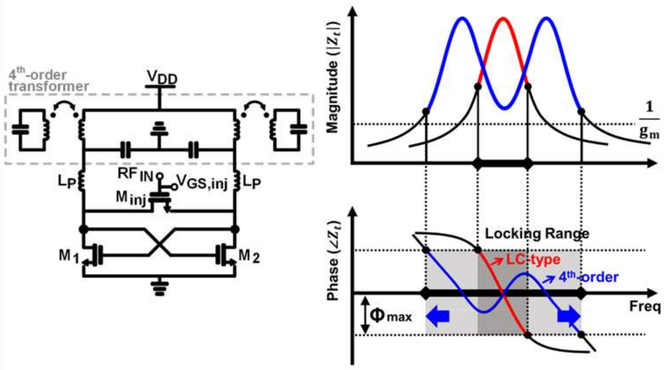
- A conventional ILFD is comprised of a cross-coupled structure, injection transistor, and resonator.
- The operating range of ILFD is determined by the following equations.
- $|Z_t| \geq \frac{1}{g_m}$, $\angle Z_t \leq \Phi_{max}$
- It is crucial to design the resonator characteristics to be within the operating conditions across a wide frequency range.

- **The narrowband characteristics of the conventional ILFD**



- A conventional ILFD is configured with an LC parallel circuit as the resonator.
- The impedance characteristics of the LC resonator have limitations in satisfying operating conditions across a wide frequency range.
- Therefore, a wide locking range technique utilizing the LC resonator is proposed in this work.

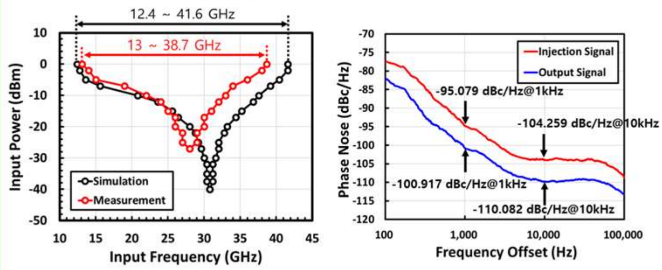
- **The schematic of 4th-order transformer based ILFD and locking range comparison with conventional ILFD**



- An ILFD structured with a resonator composed of a 4th-order transformer.
- The 4th-order transformer forms ripples in the magnitude and phase response of the impedance due to two resonances.
- Compared to the phase response of the LC resonator, the ripples generated by the 4th-order transformer enable the satisfaction of operating conditions over a broader frequency range.

Measurement results

- **Measured locking range and phase noise**



- Locking range : **13** to **38.7 GHz (99.4%)** @ 0 dBm
- Phase noise difference : **6 dBc/Hz** @ 10 kHz

- **Comparison table**

Reference	Process	Topology	Supply Voltage (V)	Operation frequency (GHz)	Locking Range (GHz) @ 0 dBm	Power (mW)	FoM** (%/mW²)
This Work	28nm	4th-order Transformer-Based	0.5	13-38.7	25.7 (99.4%)	1.85	53.73
TMTT 2017	90nm	Inductive peaking ILFD & Forward-body-bias	0.6	12-32	20 (90.9%)	2.4	37.9
JSSC 2018	65nm	4th-order Transformer-Based	1.0	27.9-53.5	25.6 (62.9%)	5.8	10.84
			0.42	32.3-61.9	29.6 (62.7%)	1.2	52.25
APMC 2019	65nm	Current reuse & 4th-order Transformer-Based	1.0	25.7-42.5	16.8 (49.3%)	1.88	26.2
TCAS-II 2021	40nm	6th-order Transformer-Based	0.6	19-48.3	29.3 (87.1%)	2.88	30.24
JSSC 2022	40nm	8th-order Transformer-Based	0.5	31-72	41 (79.6%)	1.54	51.69

** FOM = locking range(%) / [Pin(mW) * P_{DC}(mW)]

Conclusion

- A mm-wave locking range enhanced ILFD using a 4th-order transformer-based resonator is proposed.
- The ILFD shows a locking range from 13 to 38.7 GHz at 0 dBm

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