

A 0.015-mm² 60-GHz Reconfigurable Wake-Up Receiver by Reusing Multi-Stage LNAs

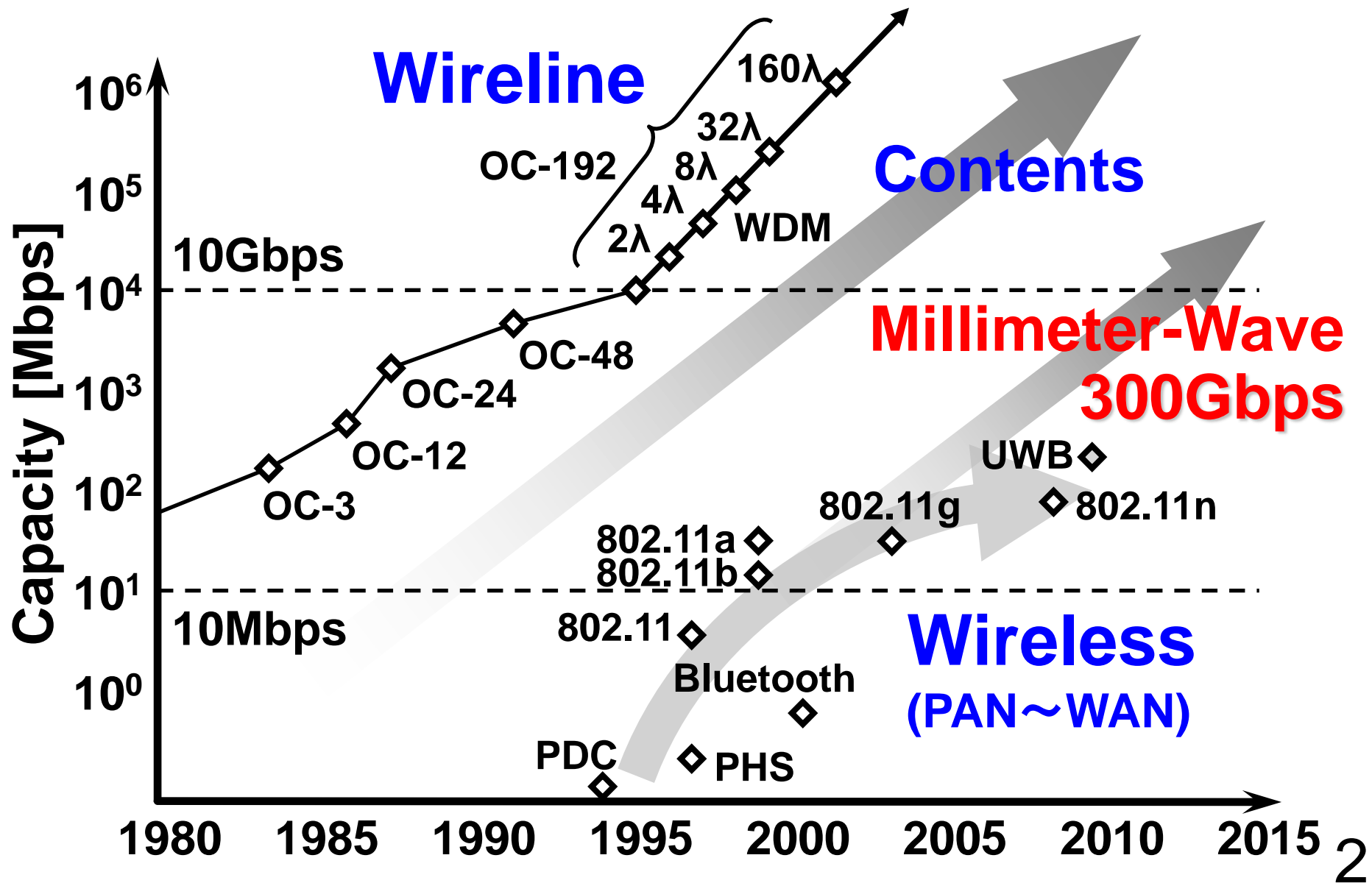
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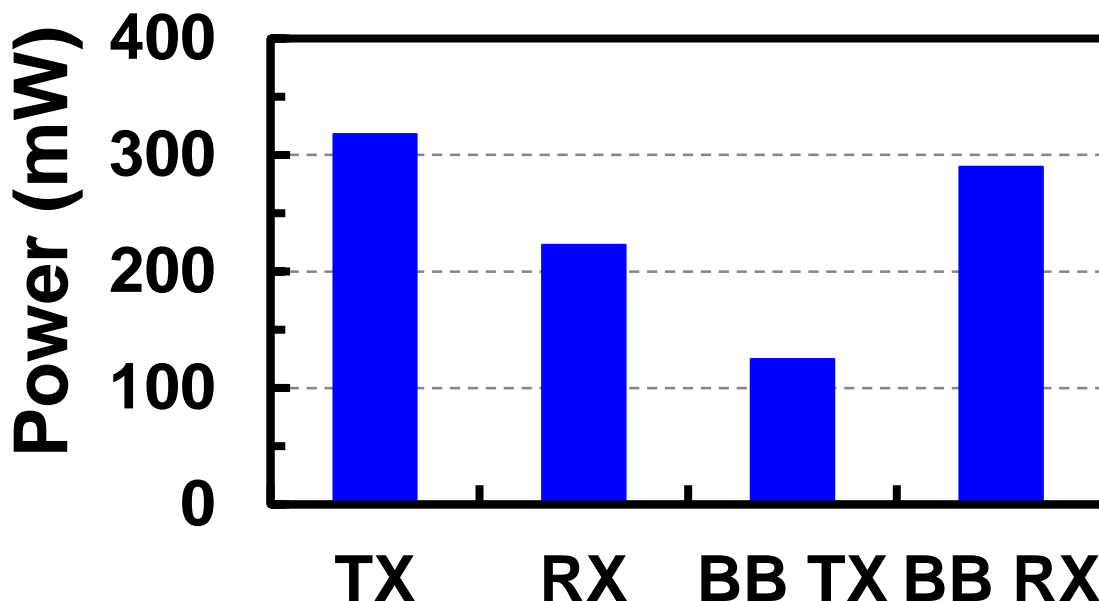
Outline

- **Background**
 - 60-GHz research field
- **Conventional Wake-Up Receivers**
- **Proposed 60-GHz WuRx**
 - Circuit design & Measurement results
- **Conclusions**

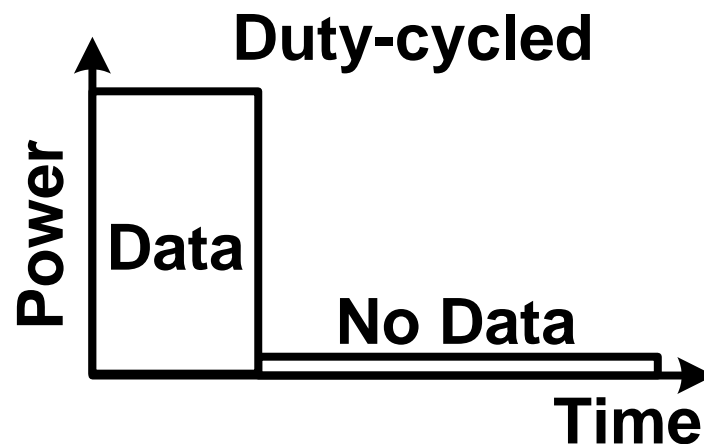
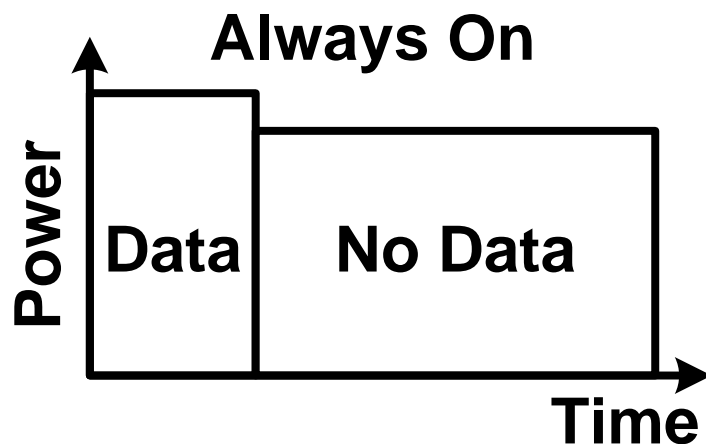
Background



60-GHz TRX for Wireless Application

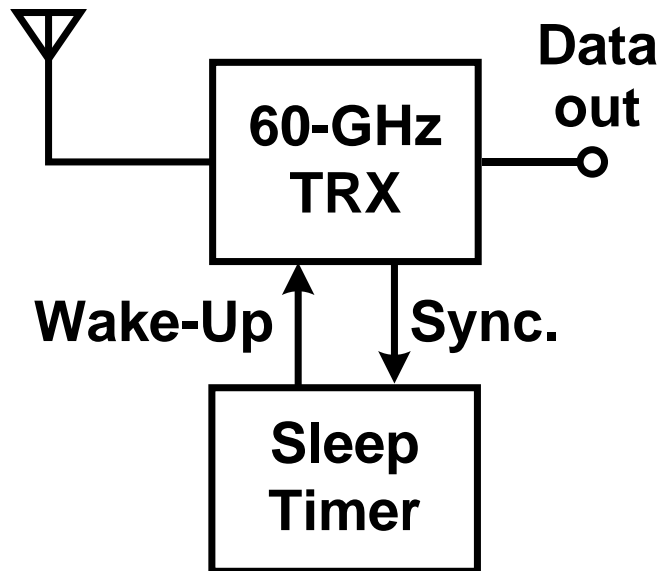


[1] K. Okada *et al.*, ISSCC 2012

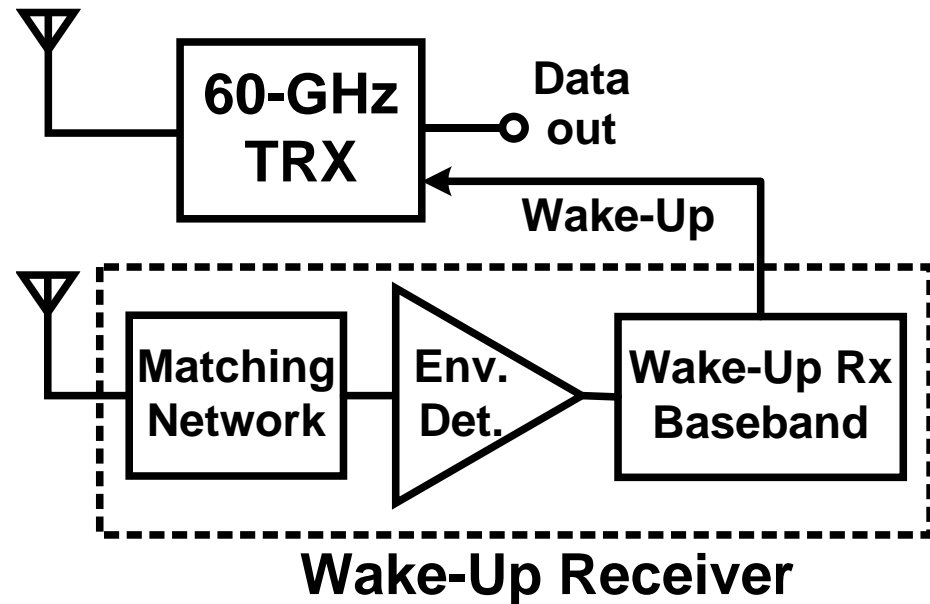


Duty cycle control is necessary

Rendezvous Scheme or Wake-Up RX?

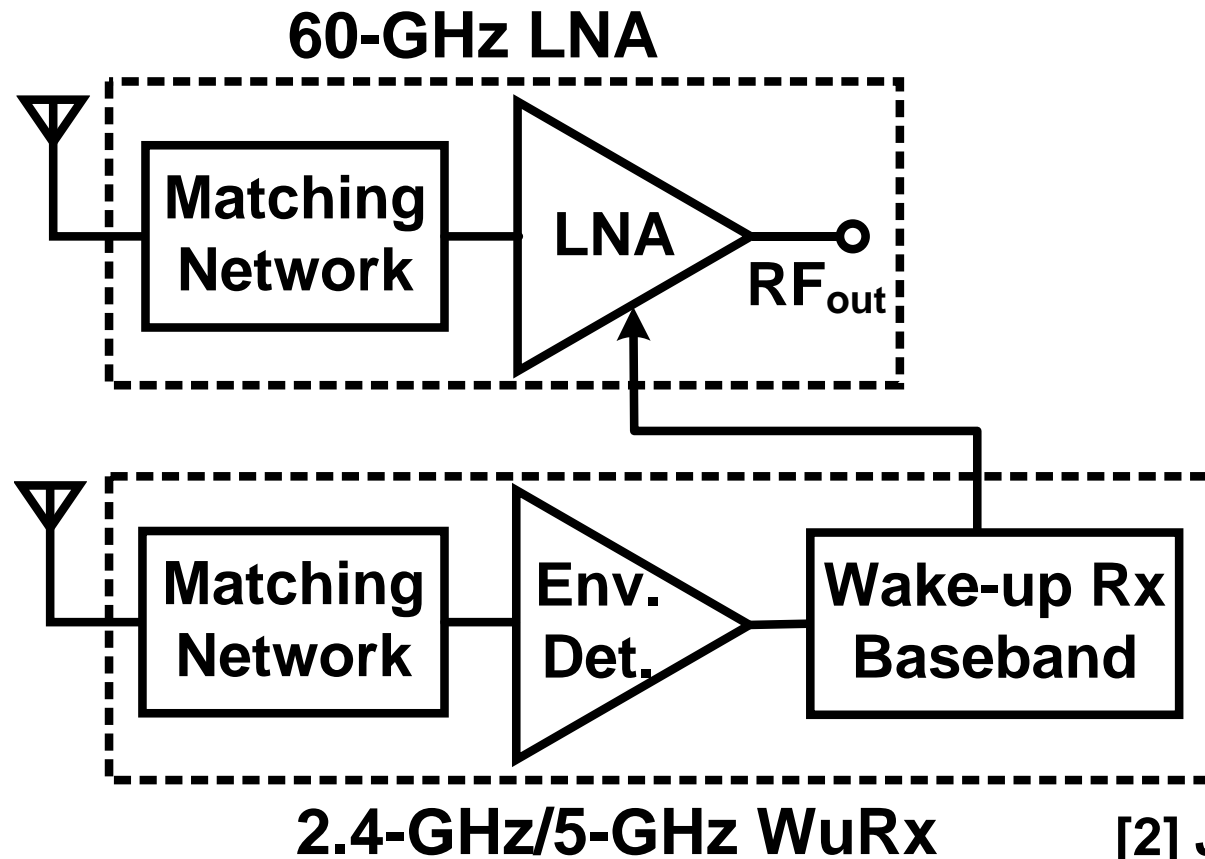


- 😊 Min. extra components
- 😞 Large latency
- 😞 Waste of power through unnecessary wakeups
- 😞 Network synchronization necessary



- 😊 Small latency
- 😊 No reference clock
- 😞 Bulky extra components
- 😞 Higher stand-by power

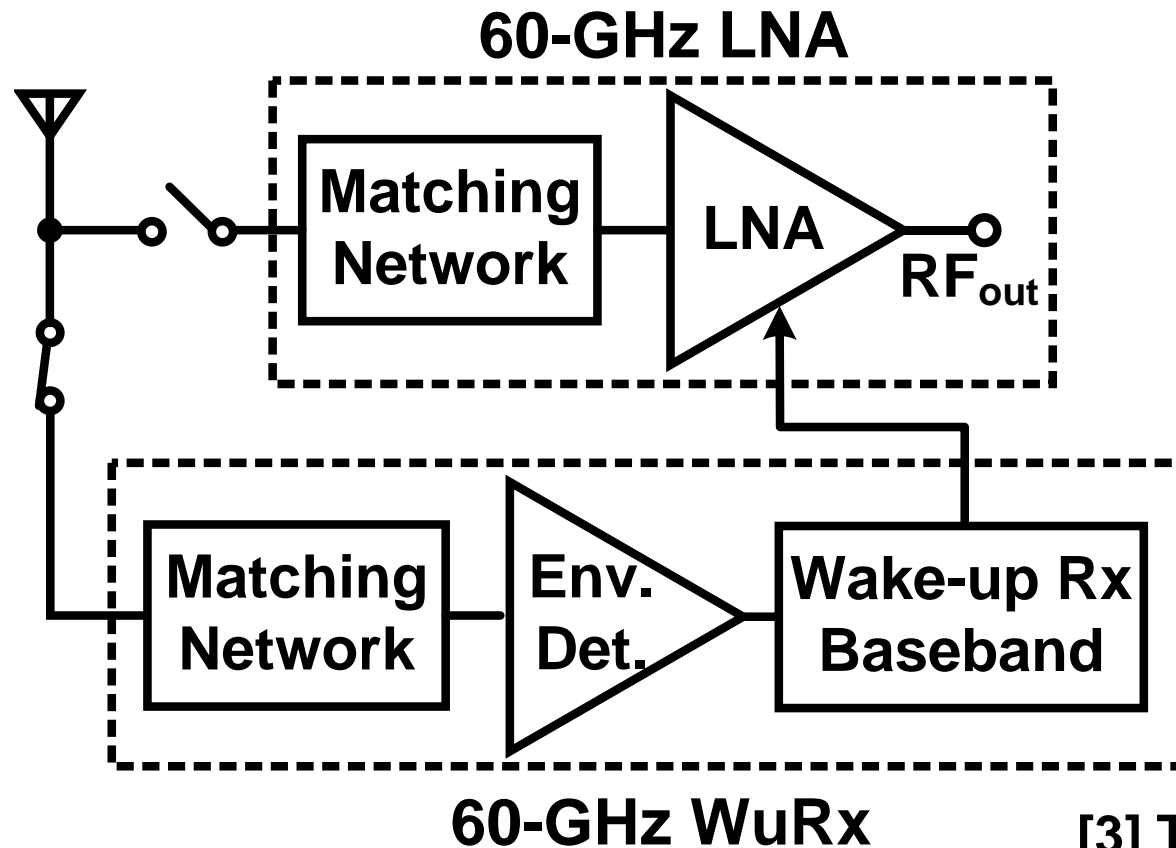
Conventional WuRxs for 60 GHz (1/2)



[2] J. Choi *et al.*,
ISSCC 2012

- 😊 High sensitivity
- 😞 Extra antenna and matching network
- 😞 Large interference at low frequency band

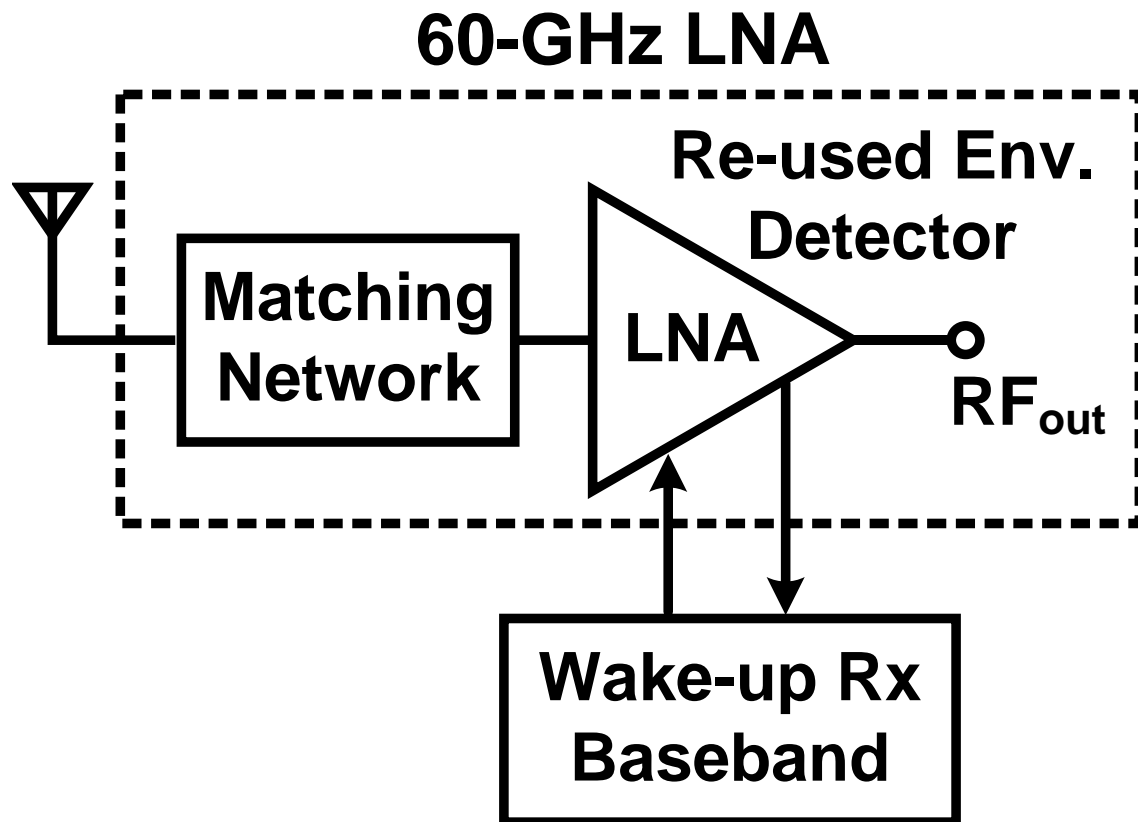
Conventional WuRxs for 60 GHz (2/2)



[3] T. Wada *et al.*,
ESSCIRC 2013

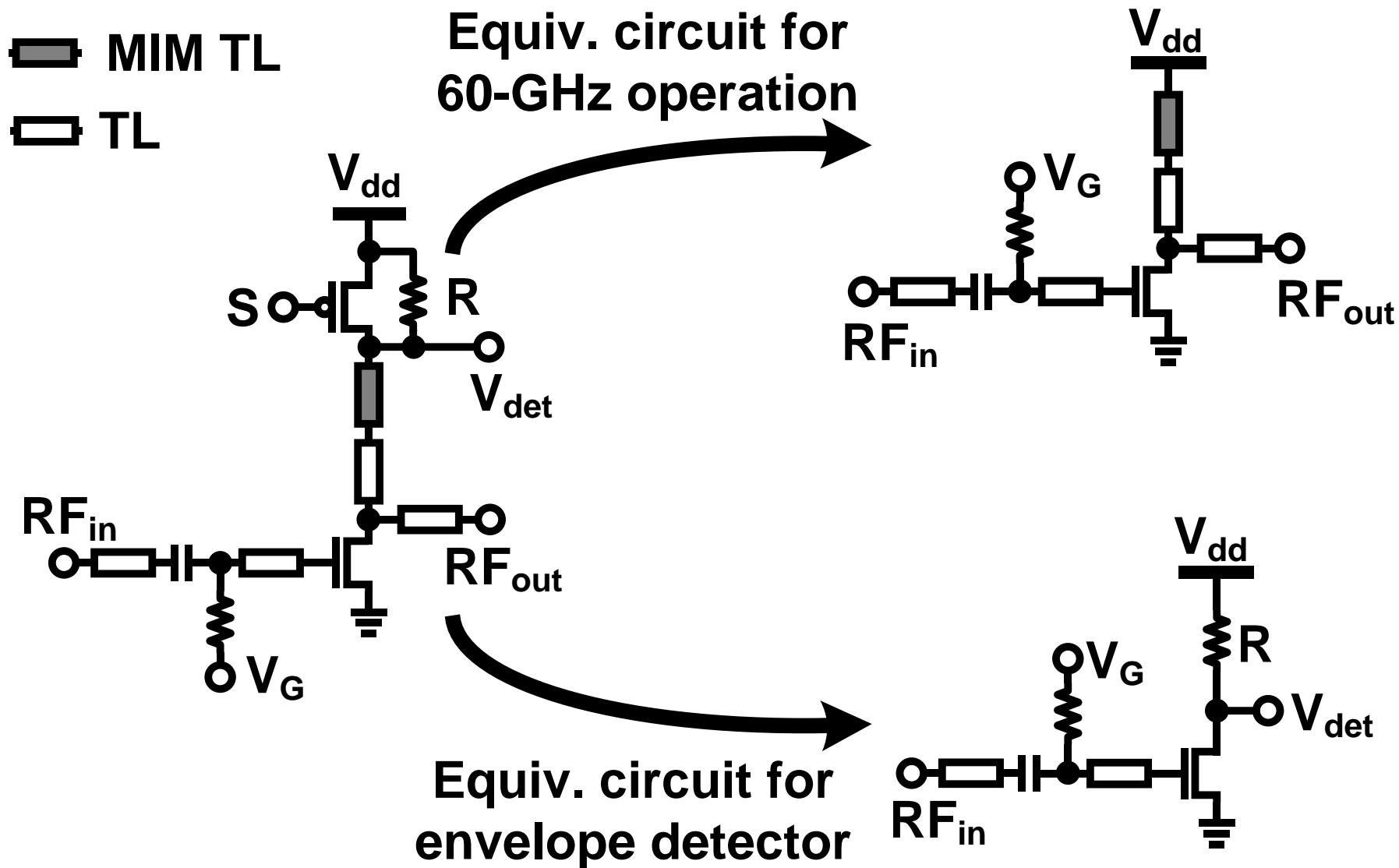
- 😊 Moderate sensitivity
- 😊 Less interference around 60 GHz
- 😞 Bulky switches and matching network

Proposed 60-GHz Wake-Up Receiver

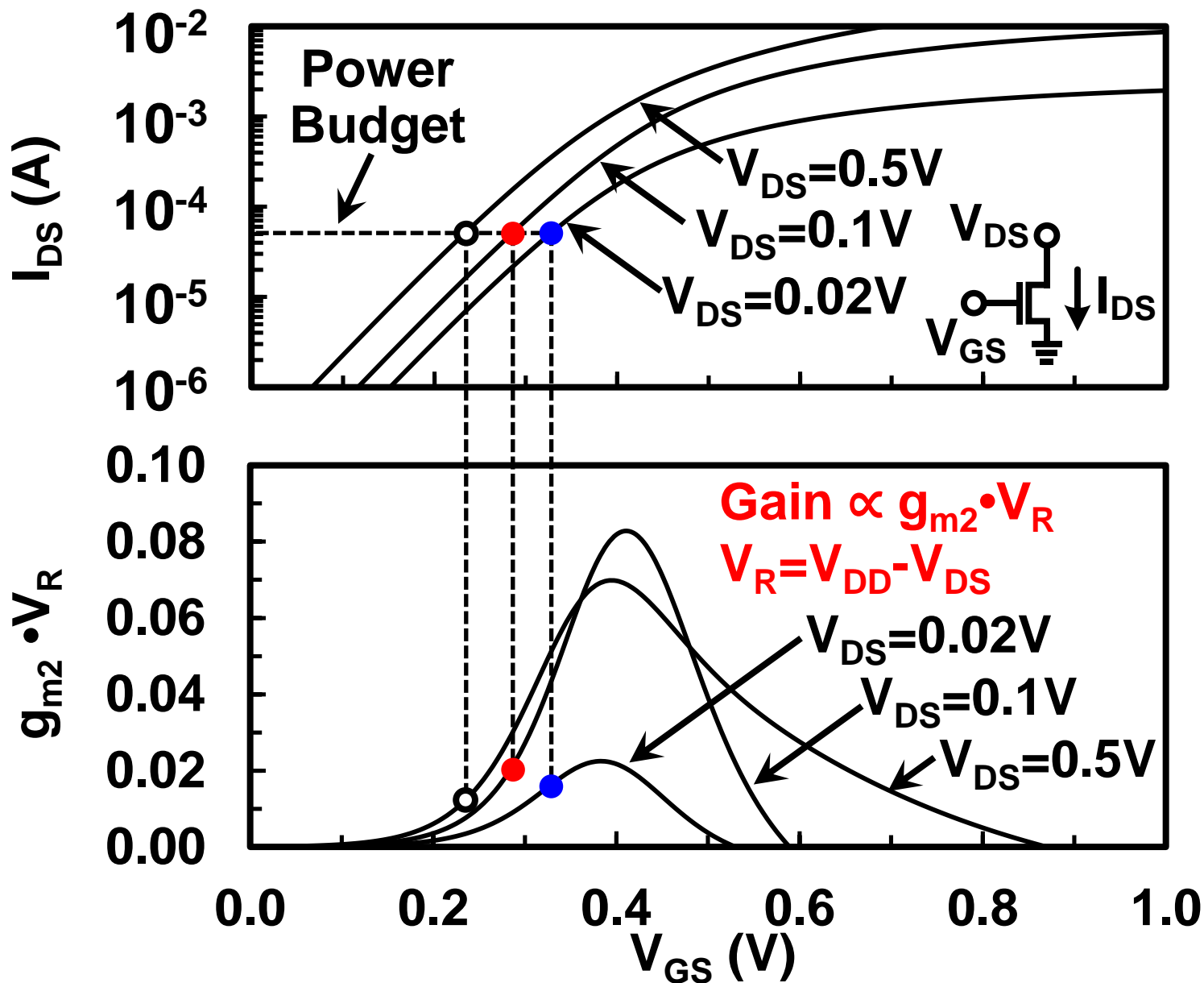


- ☺ No extra bulky components
- ☺ Less interference around 60 GHz
- ☺ Integrated sensitivity boost function

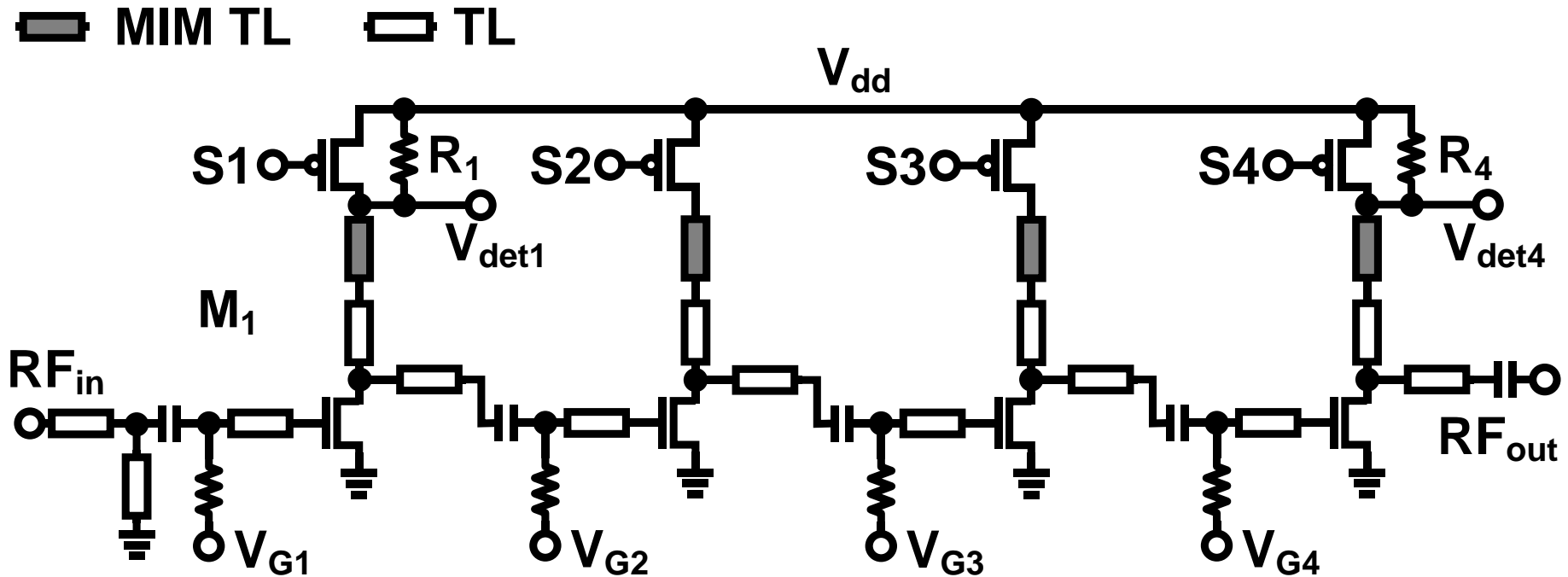
The Reused Envelope Detector Stage



Sub-Threshold Detector Optimization

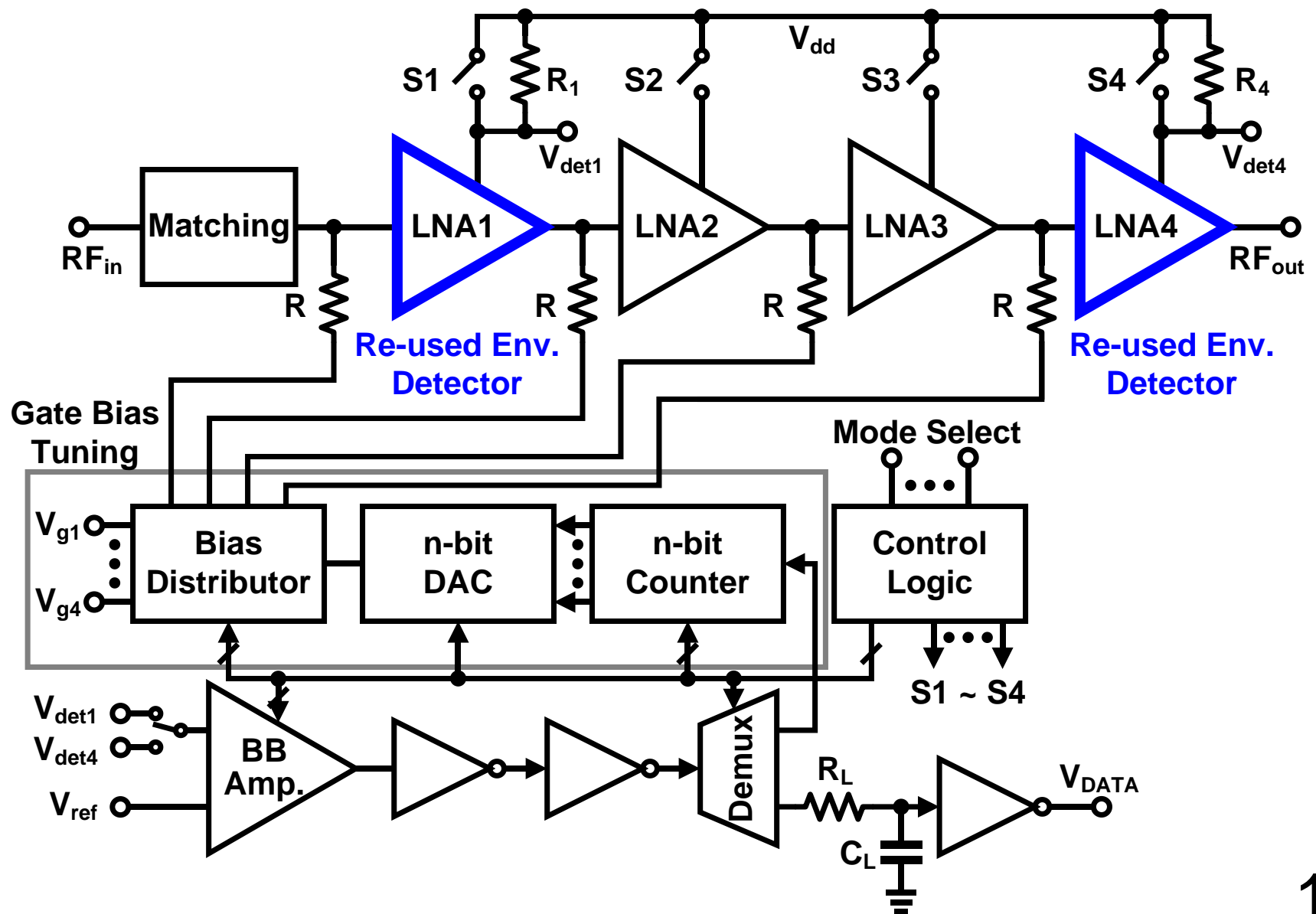


The Detailed 4-Stage Single-Ended LNA



PMOS switches with shunt resistors for reused stages

The Detailed System Block Diagram

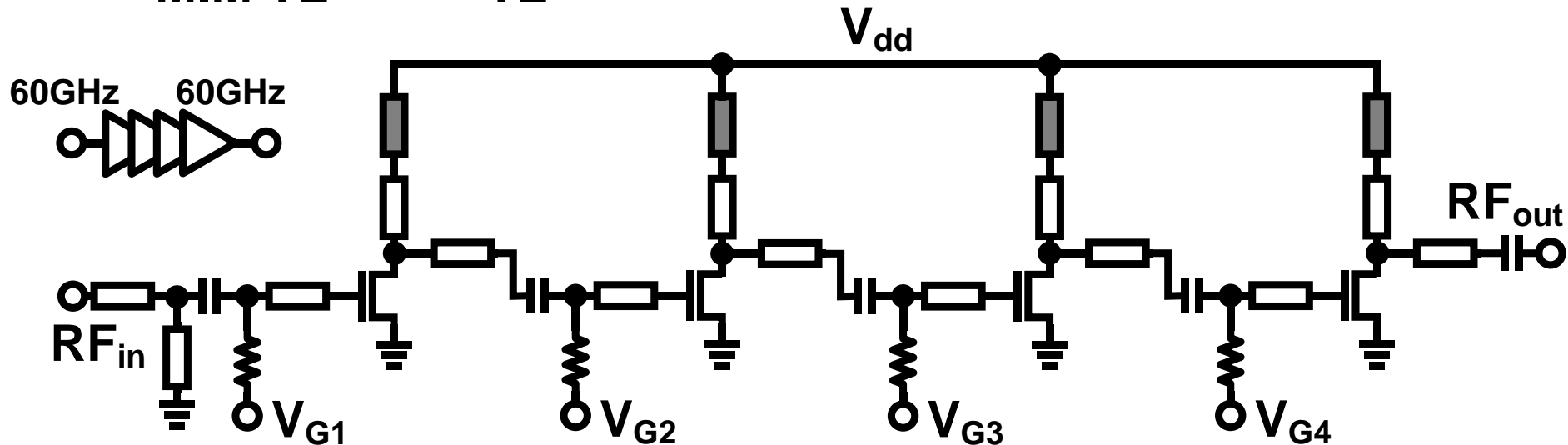


Equivalent Circuit of the 4-stage LNA

- 60-GHz LNA operation mode

■ MIM TL

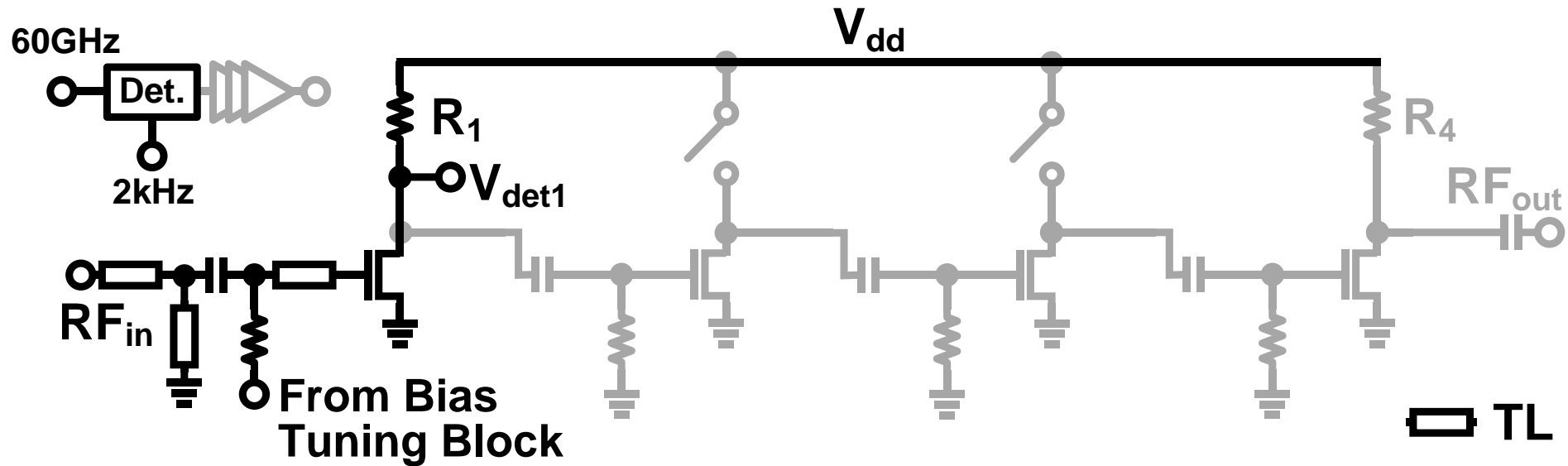
□ TL



All switches on minimizes the influence on 60-GHz LNA operation

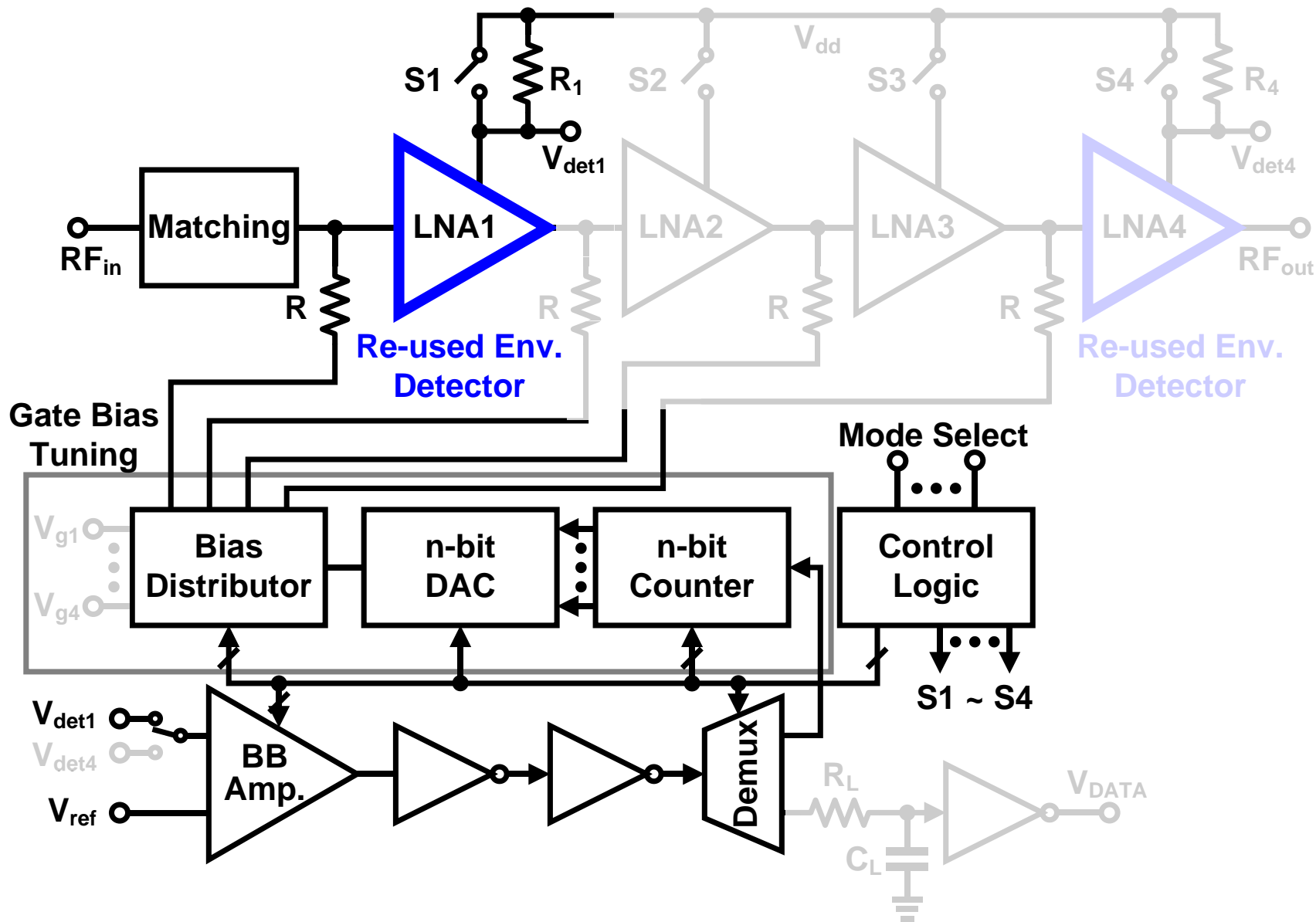
Equivalent Circuit of the 4-stage LNA

- Low-power WuRx mode

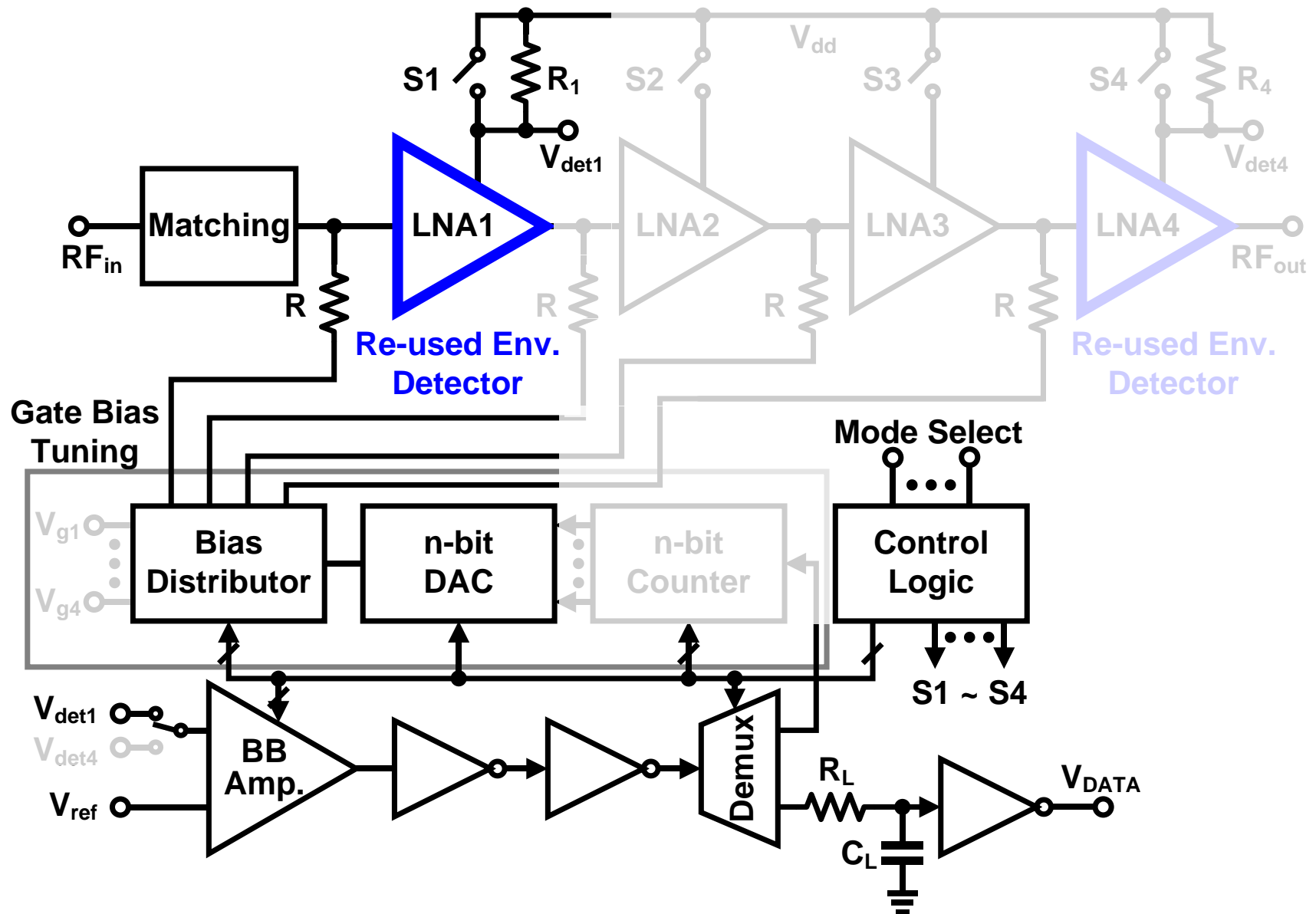


Reuse first stage as an sub-threshold envelope detector

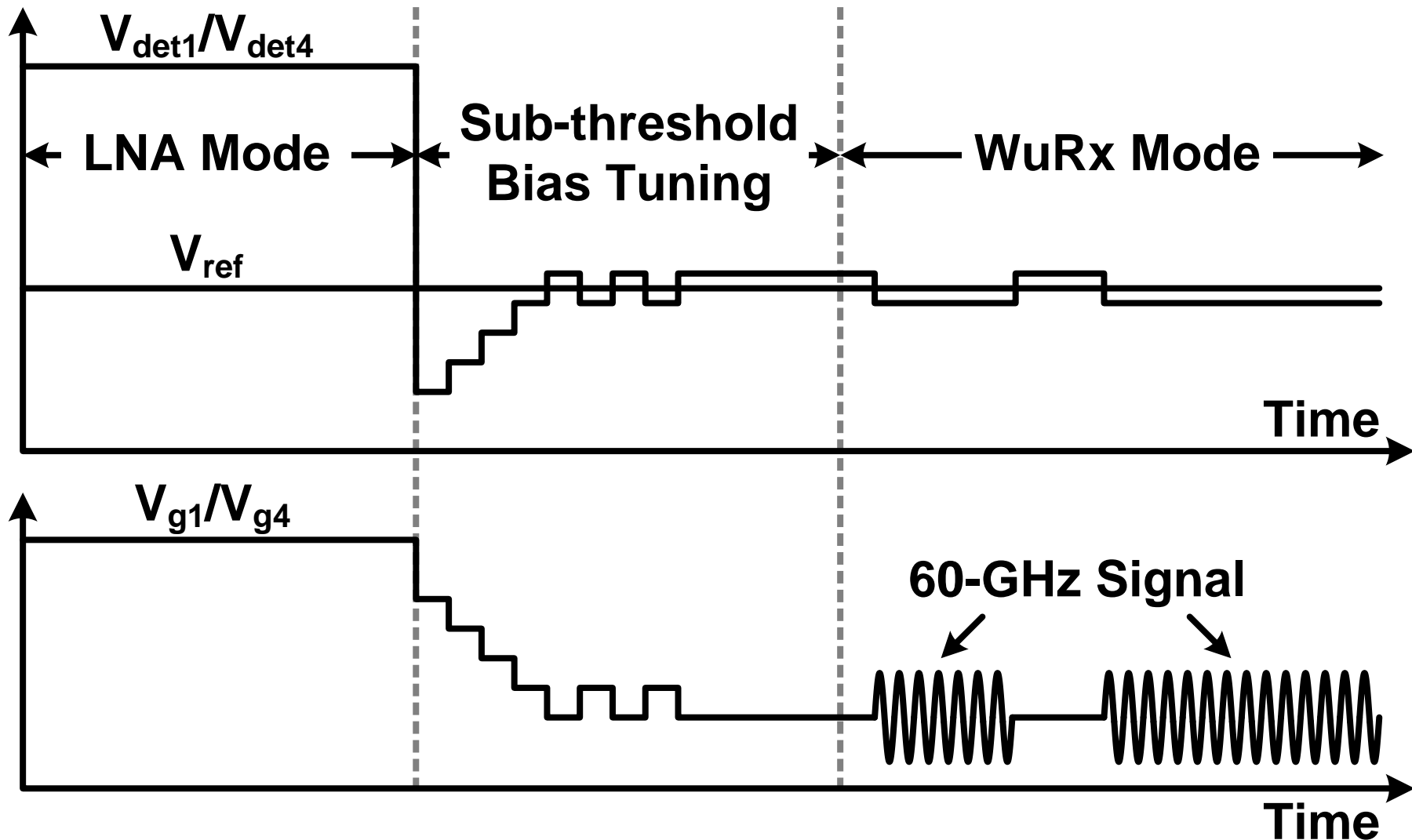
Sub-threshold Bias Tuning



Wake-Up Signal Detecting

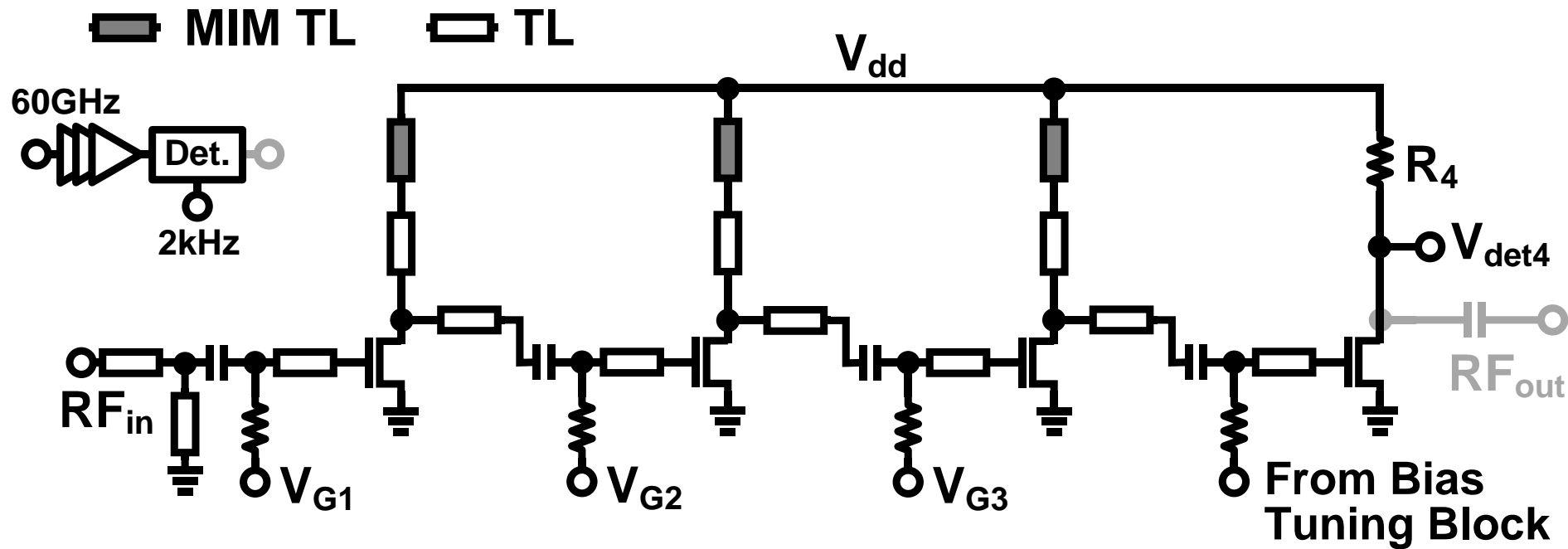


Transient Waveform of the WuRx



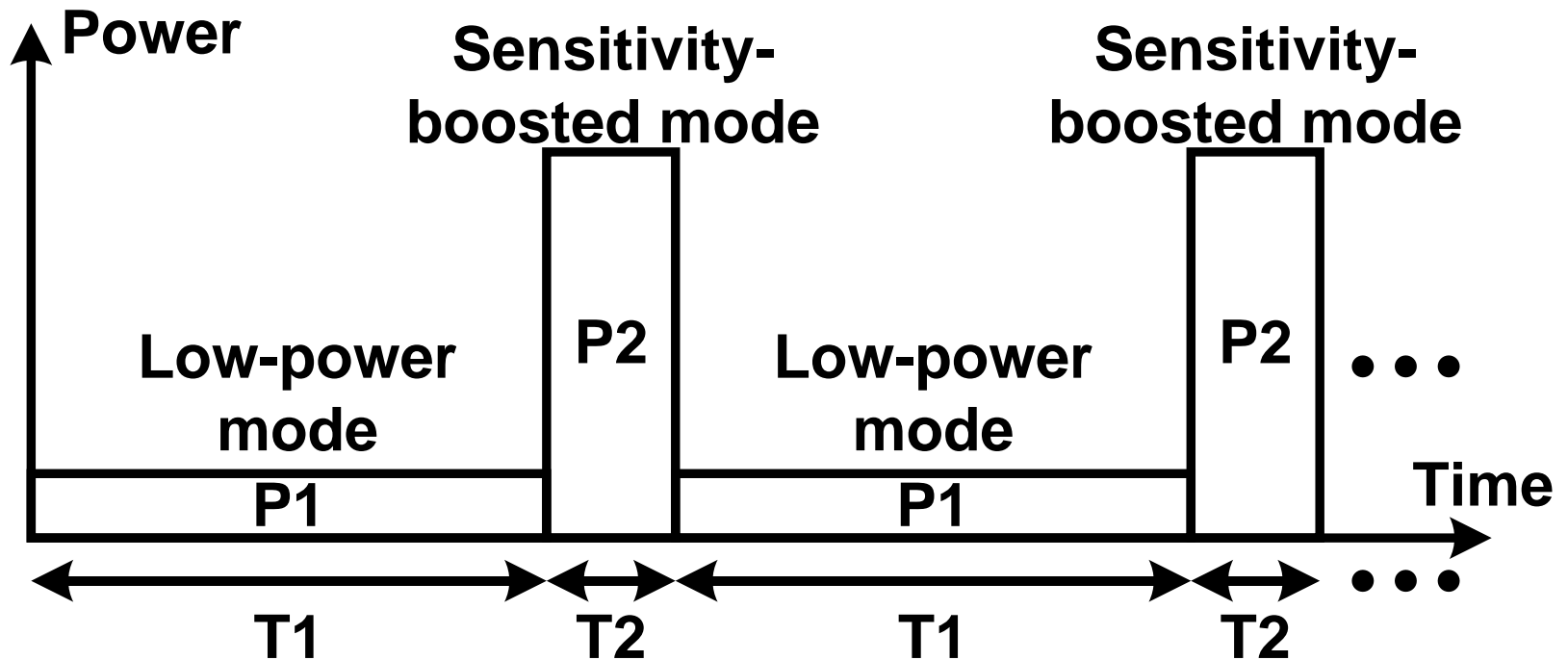
Equivalent Circuit of the 4-stage LNA

- Sensitivity-boosted WuRx mode



- Reuse last stage as a sub-threshold envelope detector
- 1st~3rd stage act as a pre-amplifier

Simplified Duty Cycle Scheme

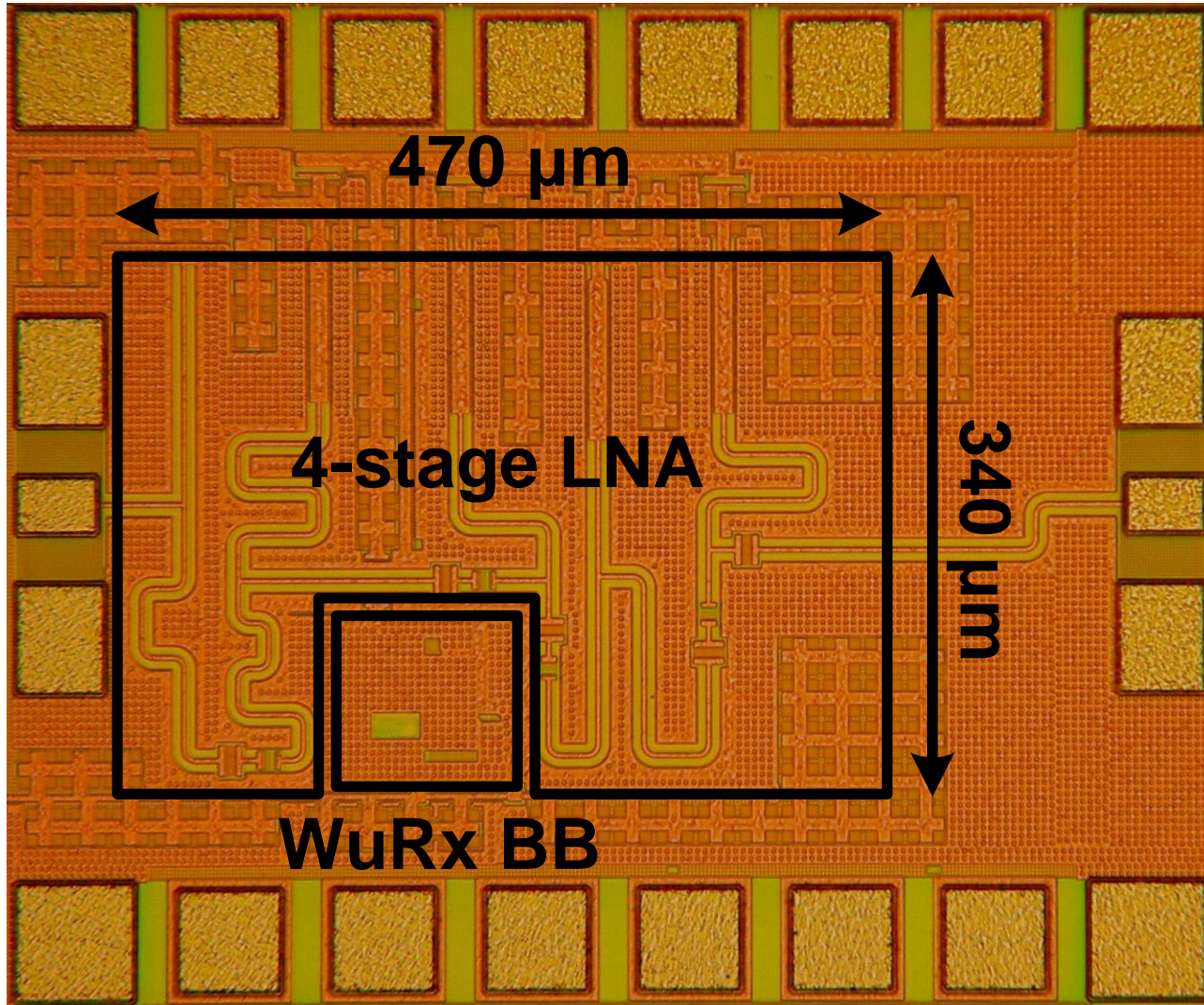


- Reduce power consumption

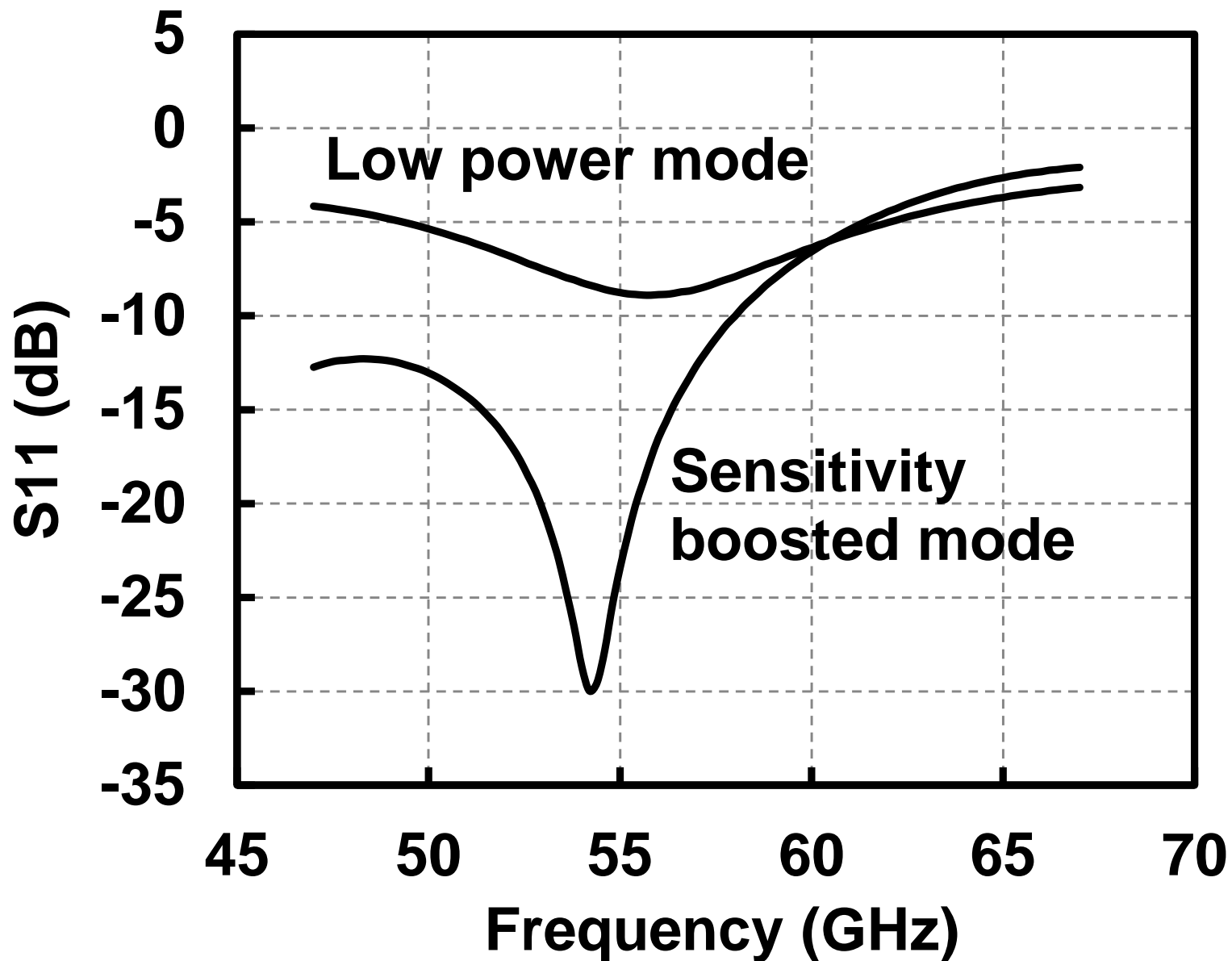
$$\text{Average Power} = \frac{T_1 \times P_1 + T_2 \times P_2}{T_1 + T_2}$$

Die Micro-Photograph

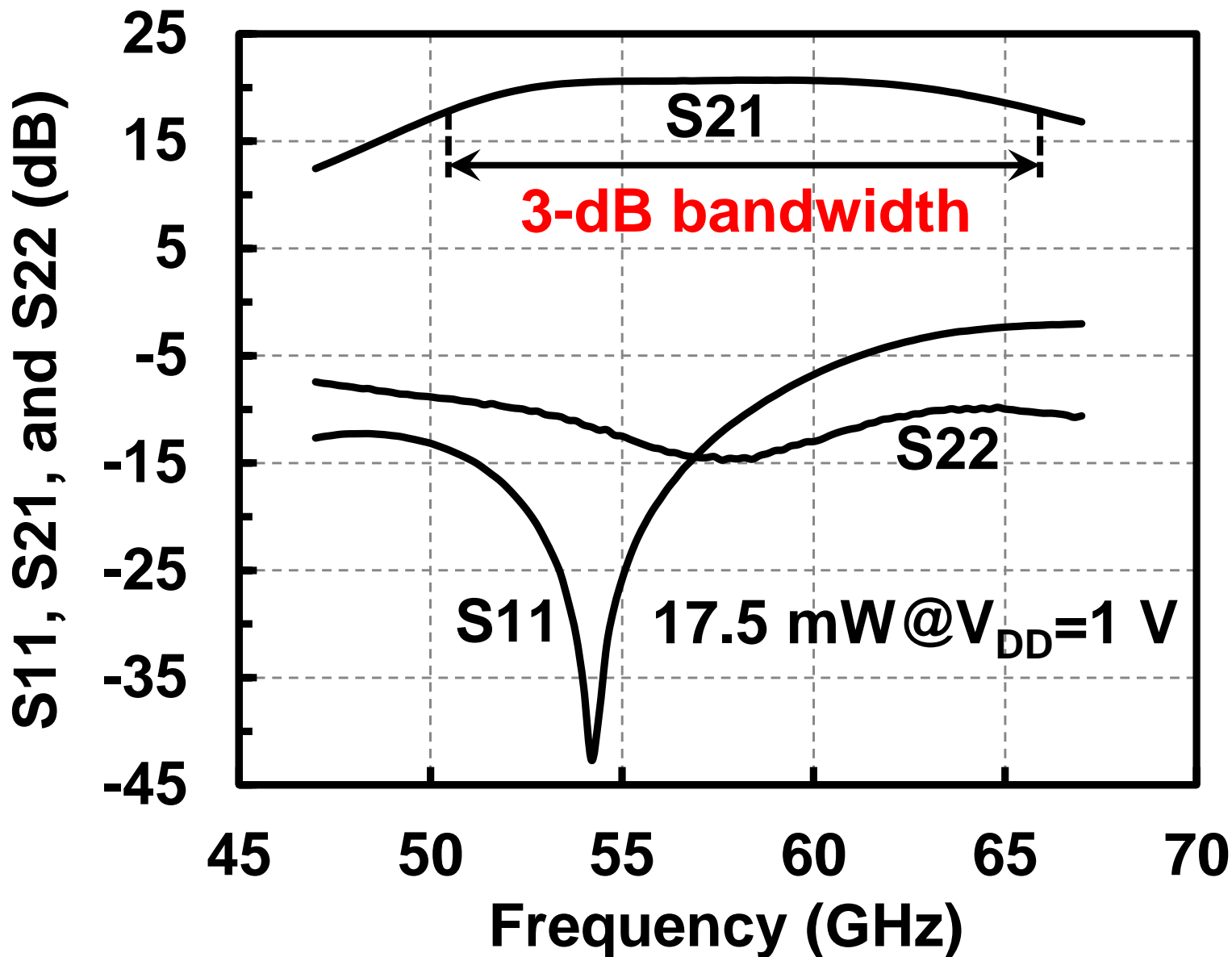
65 nm CMOS technology, **0.015 mm²**



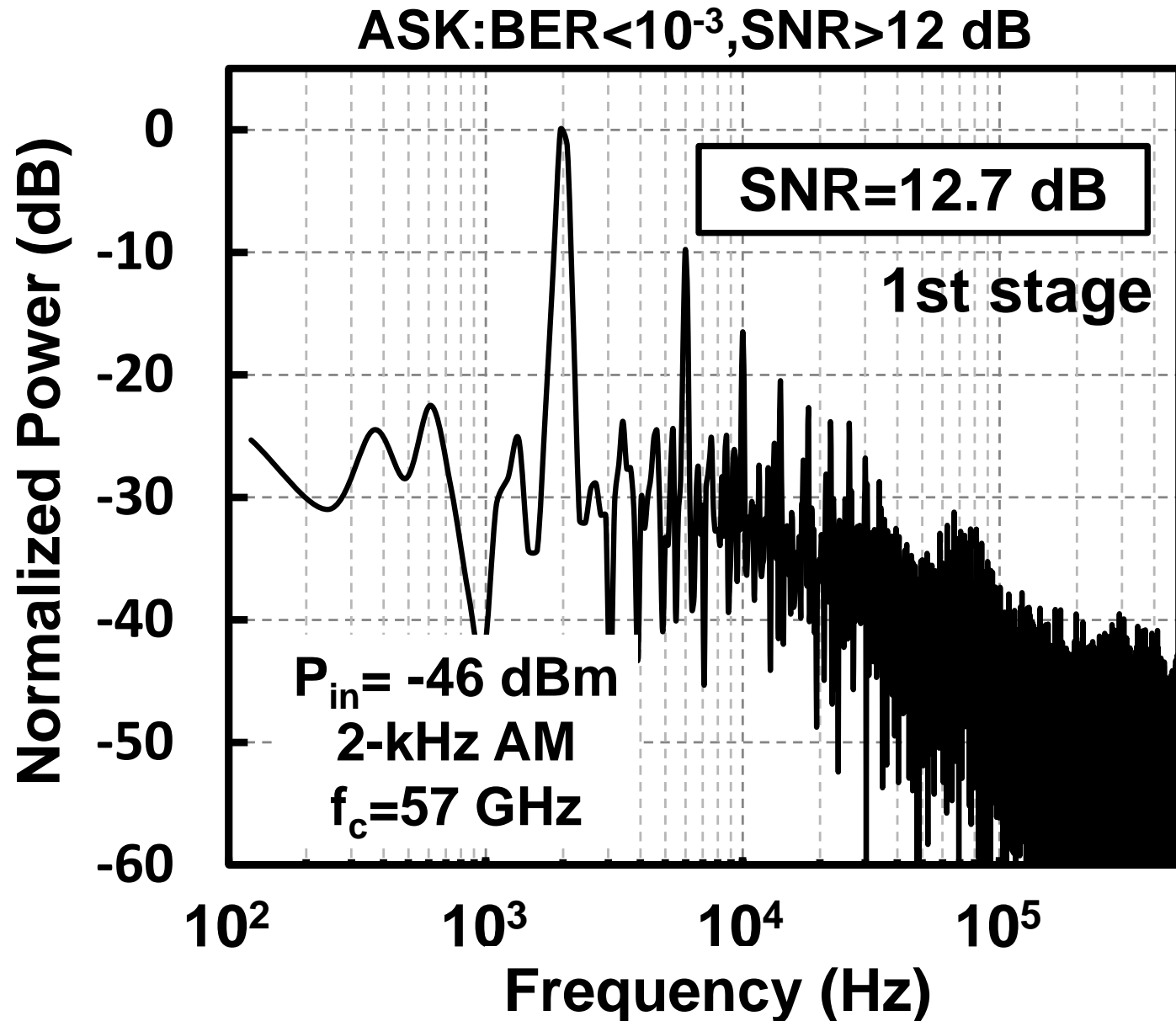
Measured S11 of WuRx



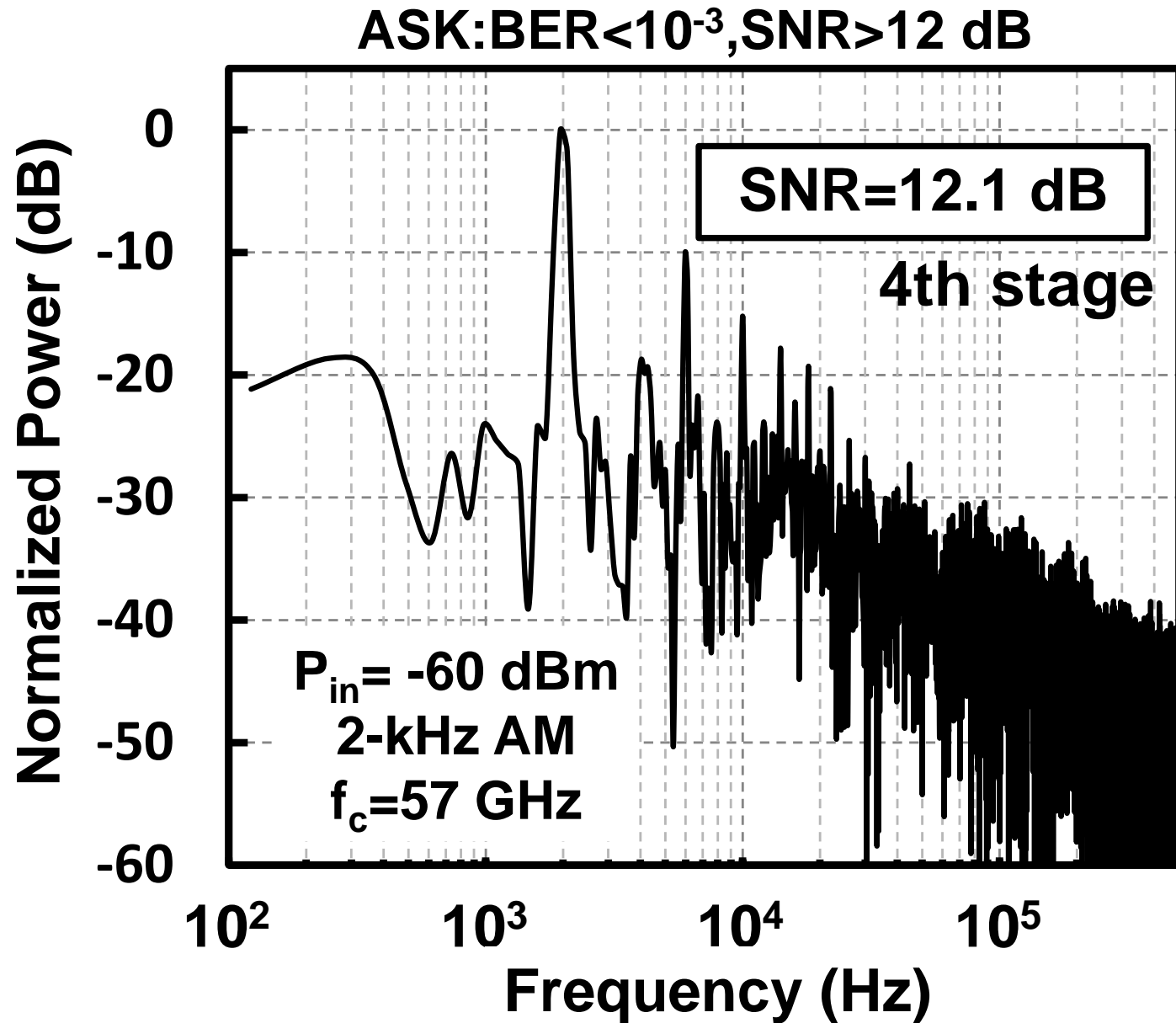
Measured S-Parameter of 60-GHz LNA



Measured Spectrum of Received Signal



Measured Spectrum of Received Signal



Performance Comparison

Ref.	Freq.	Area Overhead	Extra Antenna /Switch	Sensitivity	Power
[2]	5.8GHz	0.114mm ^{2*}	Yes	-45dBm	54μW
[3]	60GHz	1.090mm ²	Yes	—†	9μW
[4]	0.9GHz	2.886mm ²	Yes	-73dBm	9μW
[5]	0.9GHz	0.360mm ²	Yes	-80dBm	51μW
	2.4GHz			-69dBm	
This work	60GHz	0.015mm ²	No	-46dBm	64μW
				-60dBm	12.7mW

*Estimated from literature

†Only noise floor is shown

[2] J. Choi *et al.*, ISSCC 2012

[3] T. Wada *et al.*, ESSCIRC 2013

[4] D.-Y. Yoon *et al.*, JSSC 2012

[5] X. Huang *et al.*, ISSCC 2010

Conclusions

- Area-efficient WuRx for 60-GHz TRX by reusing the multi-stage LNA as envelope detectors.**
- Area overhead of only 0.015mm²,**
- No extra bulky components**
- Achieves the sensitivity of -46 dBm and -60 dBm with a static power consumption of 64 μ W and 12.7mW, respectively**