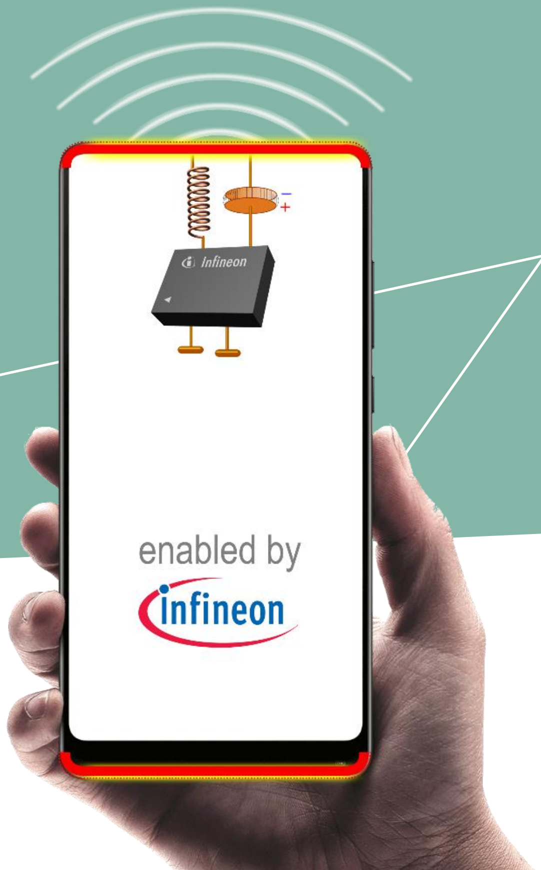
Antenna Tuning Switches for Cellular Handheld Devices



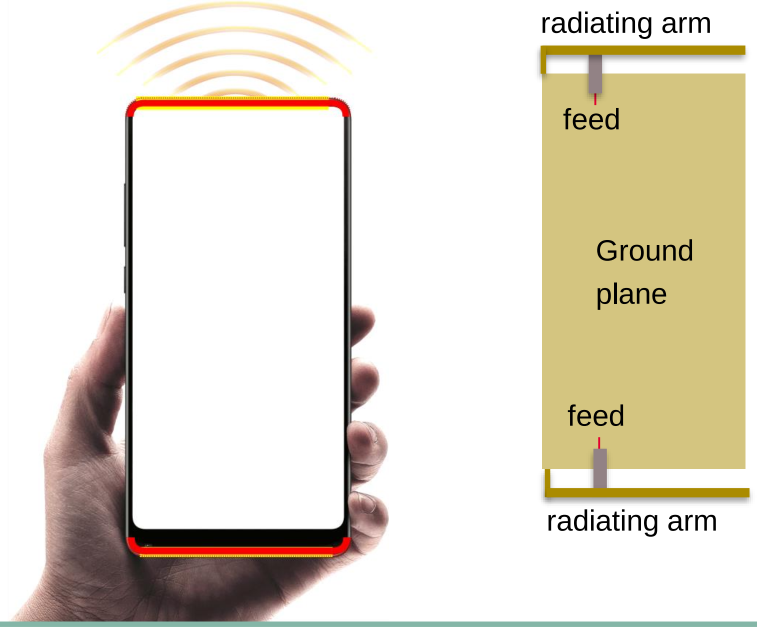
Valentyn Solomko
Infineon Technologies AG
2022-XII-9

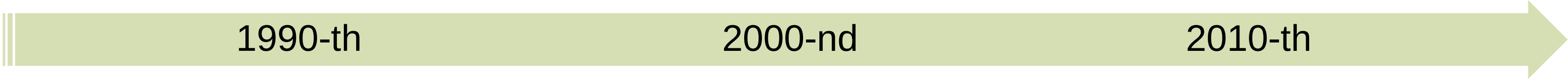
Applications for Antenna Tuners

Antenna Evolution in Cellular Phones

Monopole Antenna

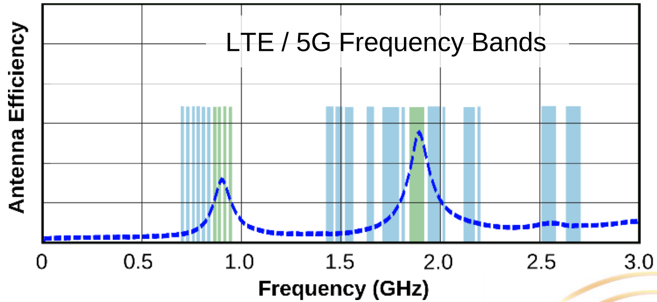
Inverted-F Antenna



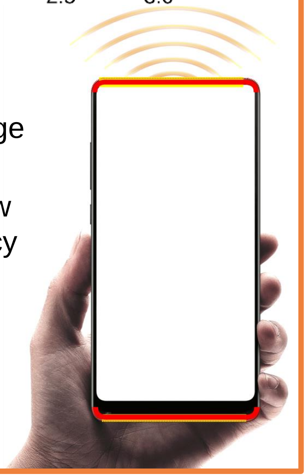


Need for Antenna Tuning

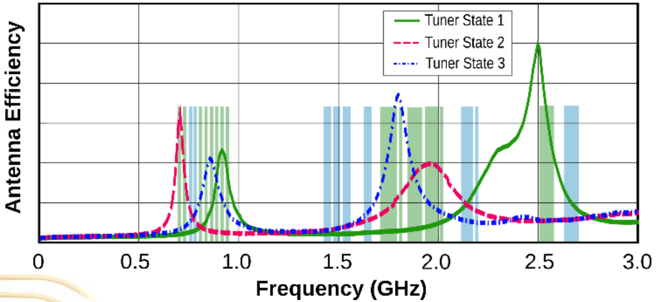
Fixed Mobile Phone Antenna

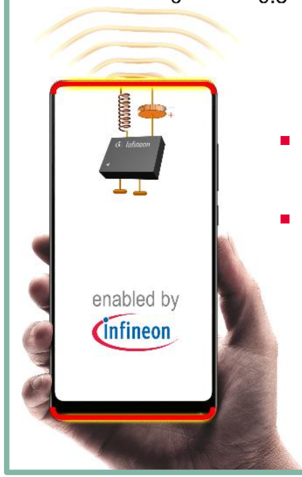


- LTE / 5G require wide frequency range coverage at sub-6 GHz
- Intrinsic integrated antennas have low power efficiency and limited frequency coverage
- User interaction with the phone may substantially change (degrade) the antenna performance



Tunable Mobile Phone Antenna



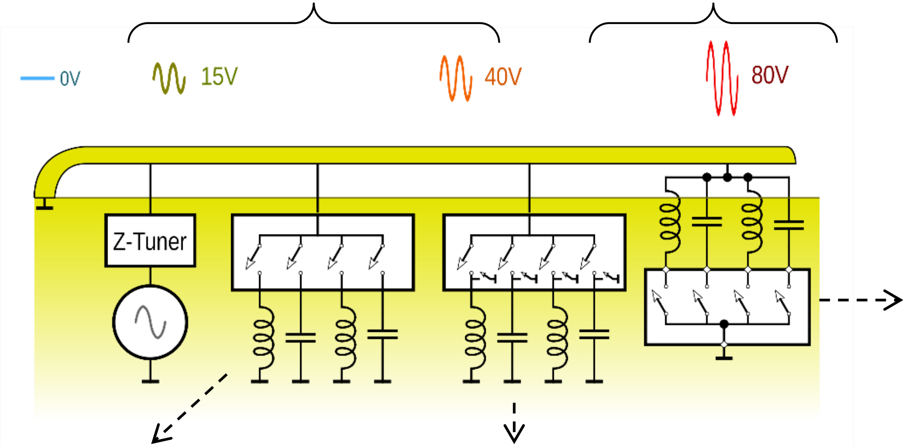


- Antenna tuning (AT) technique improves power efficiency and frequency coverage
- AT resolves the trade-off between phone appearance and electrical performance
  - AT became de-facto standard in modern smartphones

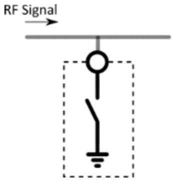
Antenna Tuning Topologies

Middle RF voltage handling class tuners
up to **45 $V_{RF.MAX}$**

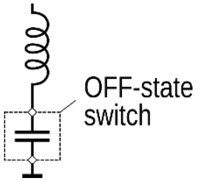
High RF voltage handling class tuners
up to **100 $V_{RF.MAX}$**



Shunt Switch

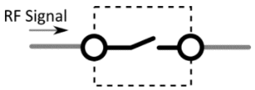


Shunts RF line to ground



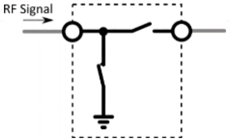
series resonance possible!

Series Switch : reflective **open**



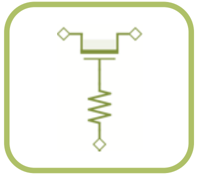
"Breaks" or "makes" the RF signal path

Series Switch : reflective **short**



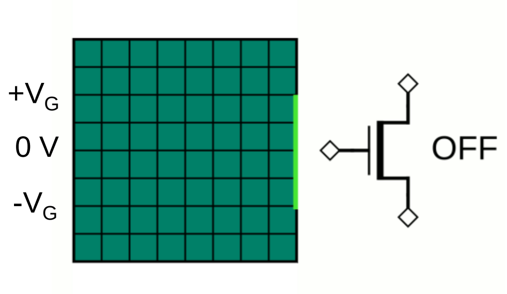
"Breaks" the RF signal path and shorts open end to ground

AT Switch Design at a Glance

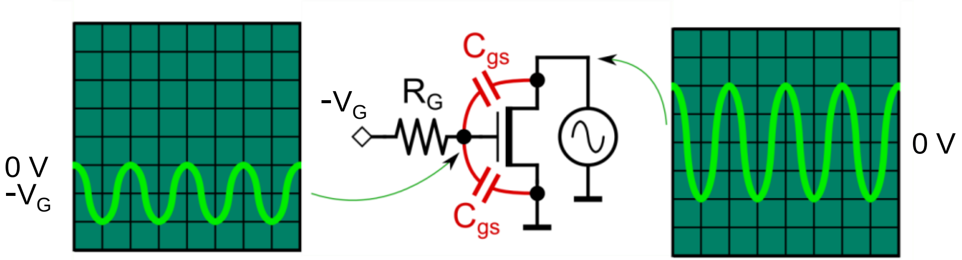


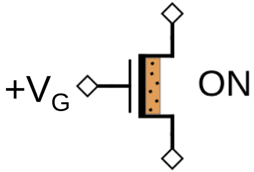
MOS Switch Transistor

RF Switch Transistor



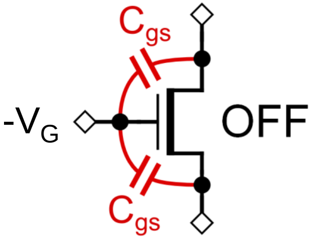
Linear RF Switch





ON-Resistance

$$R_{ON} = R_{channel}$$



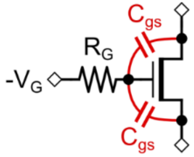
OFF-Capacitance

$$C_{OFF} = \frac{1}{2} C_{gs}$$

- $R_{ON}C_{OFF}$ is a Figure of Merit (FOM) for a given RF-switch technology
- FOM = 70 fs … 110 fs for state-of-art dedicated CMOS technologies

R_{ON} / C_{OFF} Scaling

$$C_{OFF1} = \frac{1}{2} C_{gs}$$



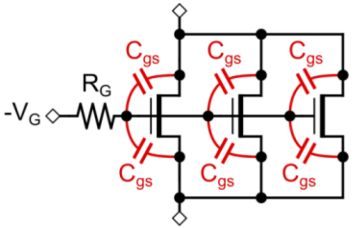
$$R_{ON1} = R_{channel}$$

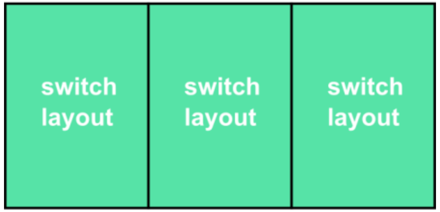
- R_{ON}/C_{OFF} are linearly-scaled with transistor width
- R_{ON} and C_{OFF} are inversely-proportional to each other
- Switches with lower R_{ON} are **larger in size**
- Ratio $R_{ON} \cdot C_{OFF}$ for switches remain constant no matter how transistors are sized:

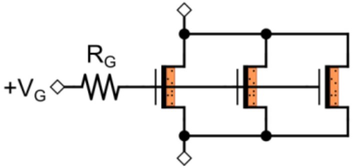
$$R_{ON1} C_{OFF1} = R_{ON2} C_{OFF2} = FOM$$

However, $R_{ON} \cdot C_{OFF}$ ratio of actual product is **higher** due to routing/package/PCB parasitics!

$$C_{OFF2} = 3 \cdot \frac{1}{2} C_{gs}$$

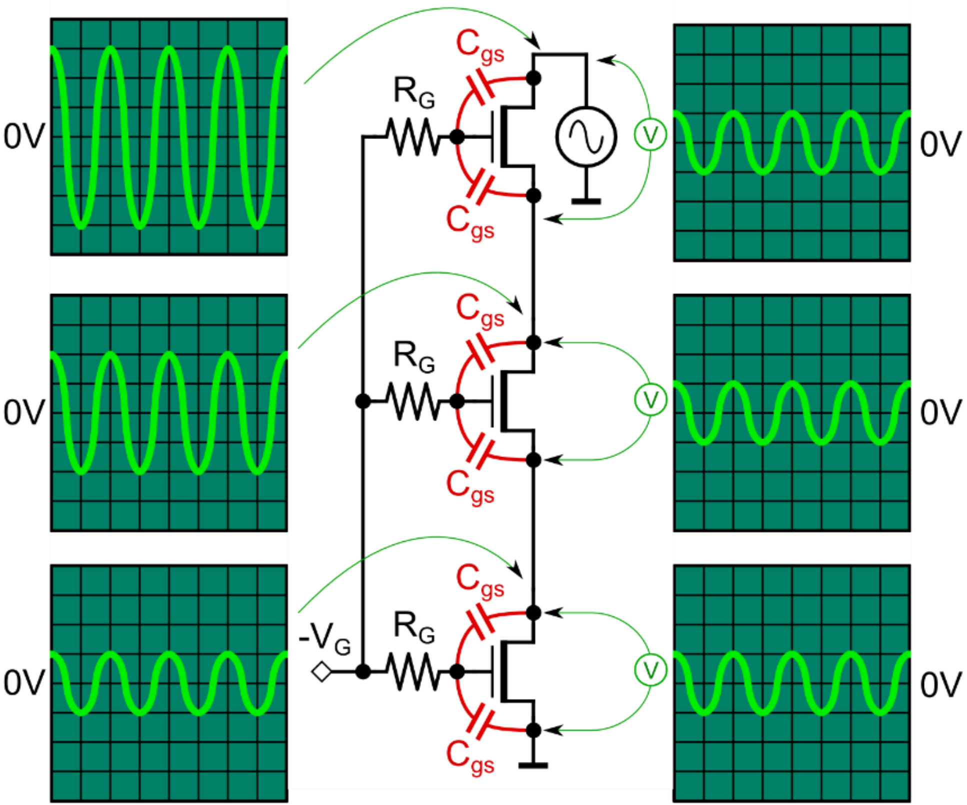






$$R_{ON2} = \frac{1}{3} R_{channel}$$

High RF Voltage Handling



- In state-of-art dedicated switch technologies
  - $R_{ON}C_{OFF}$ = 70 fs …110 fs
  - Single transistor can handle 3 V…4 V RF voltage

- Number of stacked devices is linearly-proportional to maximum RF voltage
- Total R_{ON} and C_{OFF} is partitioned according to the number of stacked devices:

$$R_{ON\Sigma} = R_{ON} \cdot \mathrm{STK}$$
$$C_{OFF\Sigma} = C_{OFF} / \mathrm{STK}$$

- $R_{ON} \cdot C_{OFF}$ product remain constant no matter how transistors are sized and stacked:

$$R_{ON\Sigma} \cdot C_{OFF\Sigma} = R_{ON} \cdot C_{OFF}$$

- High-voltage switches are **large in size**

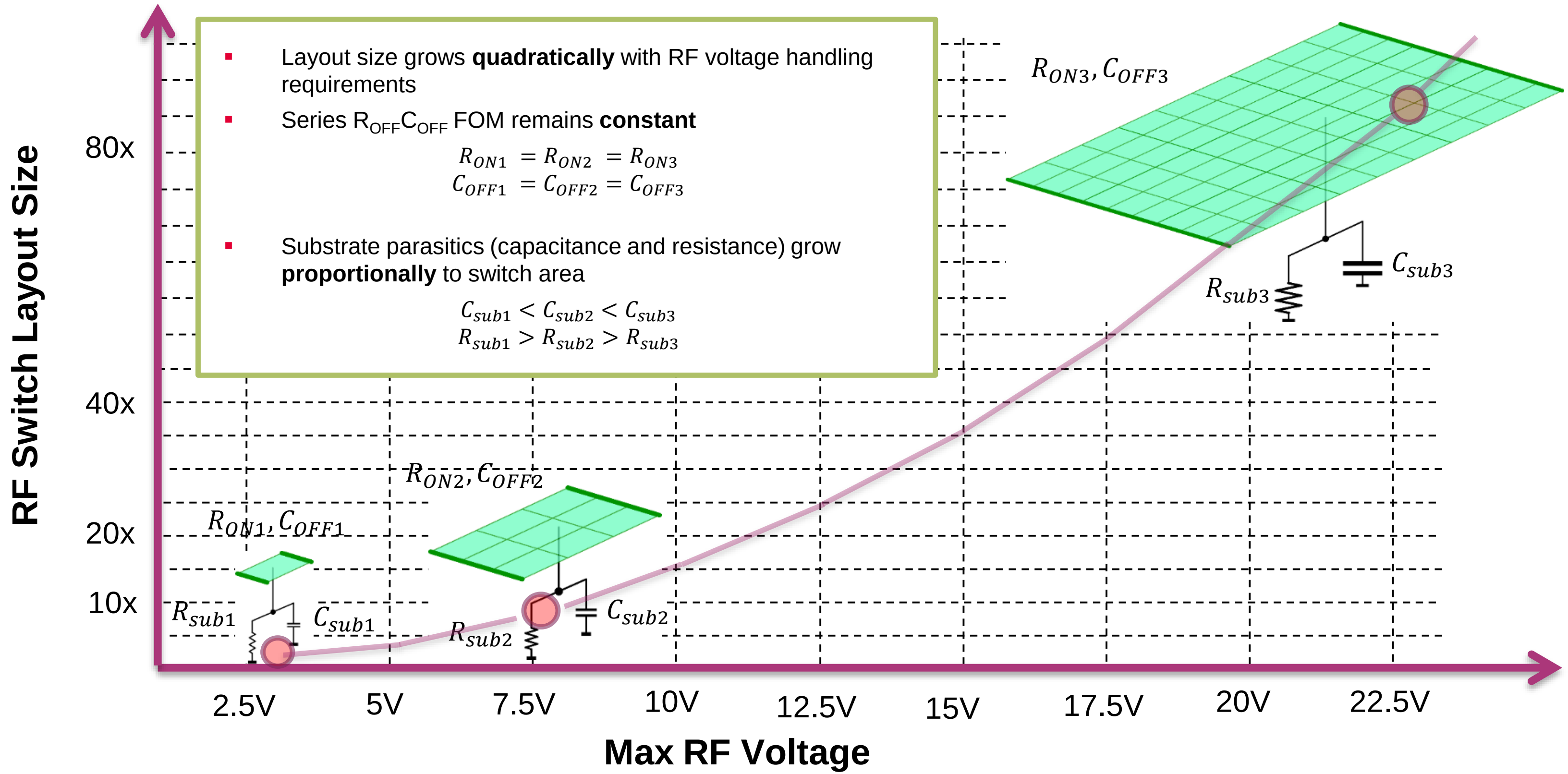
High RF Voltage Handling – Layout Scaling and Parasitics

- Layout size grows **quadratically** with RF voltage handling requirements
- Series $R_{OFF}C_{OFF}$ FOM remains **constant**

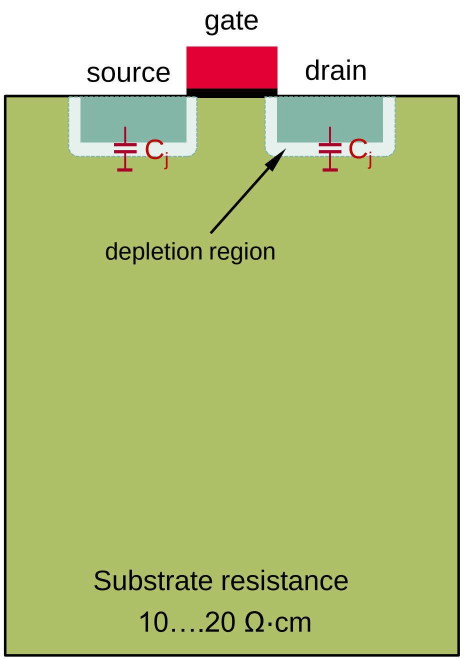
$$R_{ON1} = R_{ON2} = R_{ON3}$$
$$C_{OFF1} = C_{OFF2} = C_{OFF3}$$

- Substrate parasitics (capacitance and resistance) grow **proportionally** to switch area

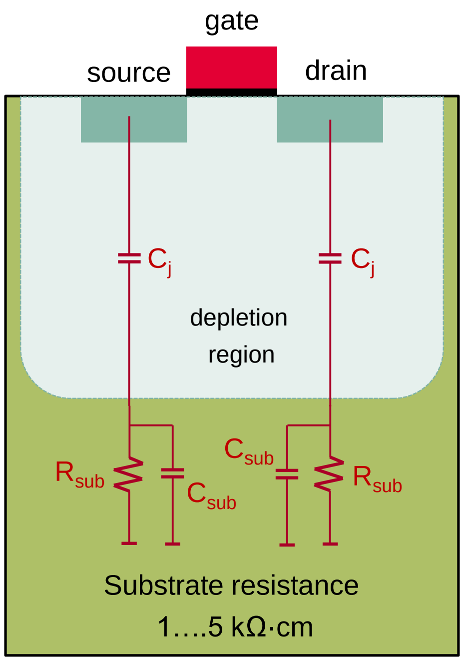
$$C_{sub1} < C_{sub2} < C_{sub3}$$
$$R_{sub1} > R_{sub2} > R_{sub3}$$



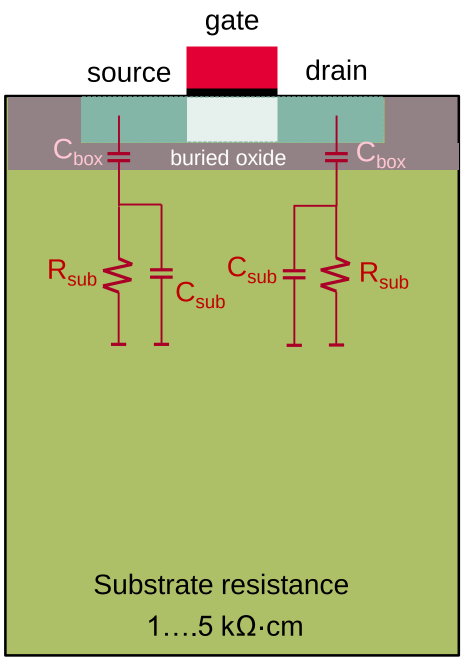
Dedicated versus Standard MOS Transistor



Standard bulk-CMOS



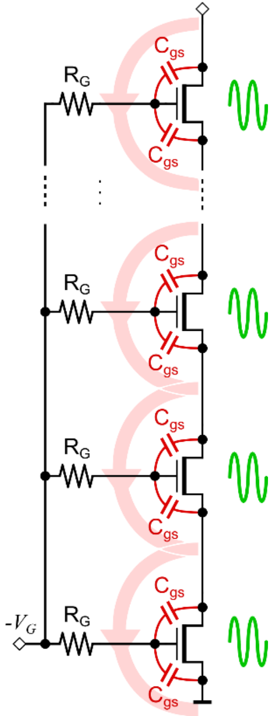
Dedicated RF switch bulk-CMOS



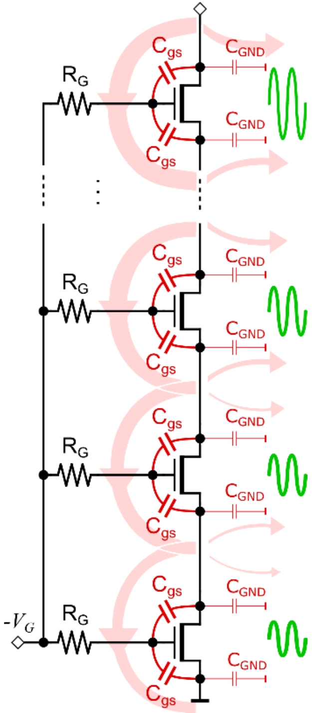
Dedicated RF switch SOI-CMOS

Effect of Substrate Parasitics and Compensation Thereof

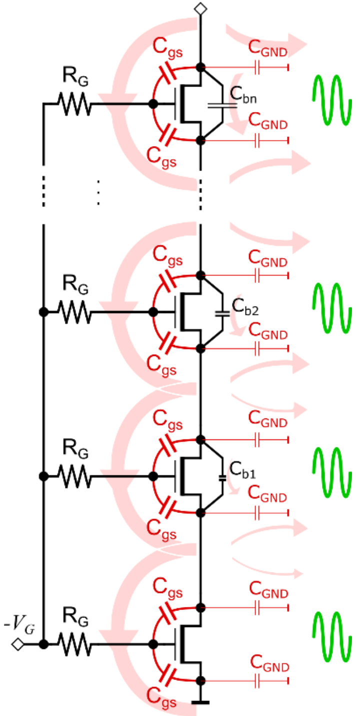
Perfect Voltage Division



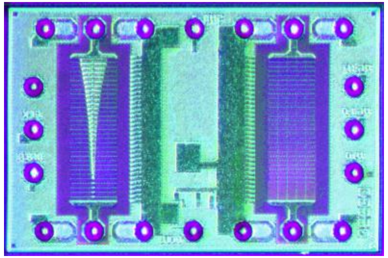
Distorted Voltage Division

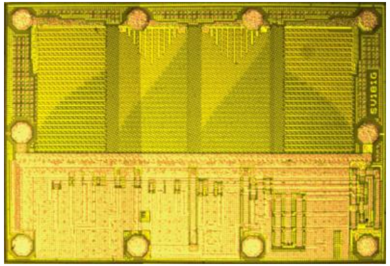


Equalized Voltage Division

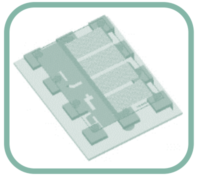


$$C_{bi} = \frac{i\,(i-1)}{2} \cdot C_{GND}$$

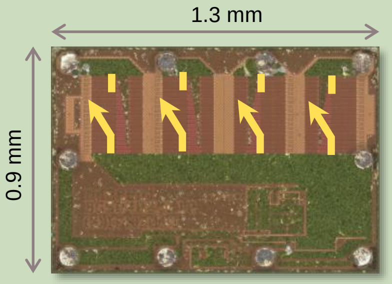
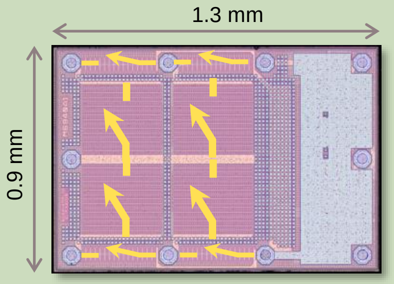
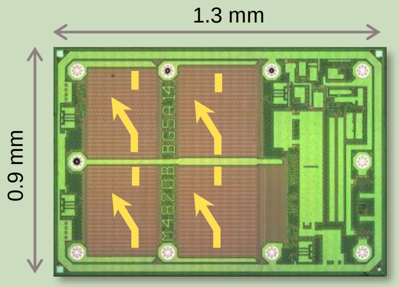
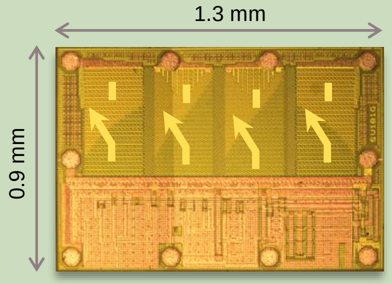




Tuner Products Examples



Antenna Tuner Examples

	Shunt Switch	Series Switch : reflective **short**	Series Switch : reflective **open**
$V_{RF.MAX}$ **45 V**			
$V_{RF.MAX}$ **80 V**			

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