High frequency measurements using wafer level techniques

Measuring Low dK/dF Materials from 1 GHz to 1 THz

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National Institute of Standards and Technology

17TH INTERNATIONAL CONFERENCE ON • APRIL 12-15, 2021
DEVICE PACKAGING
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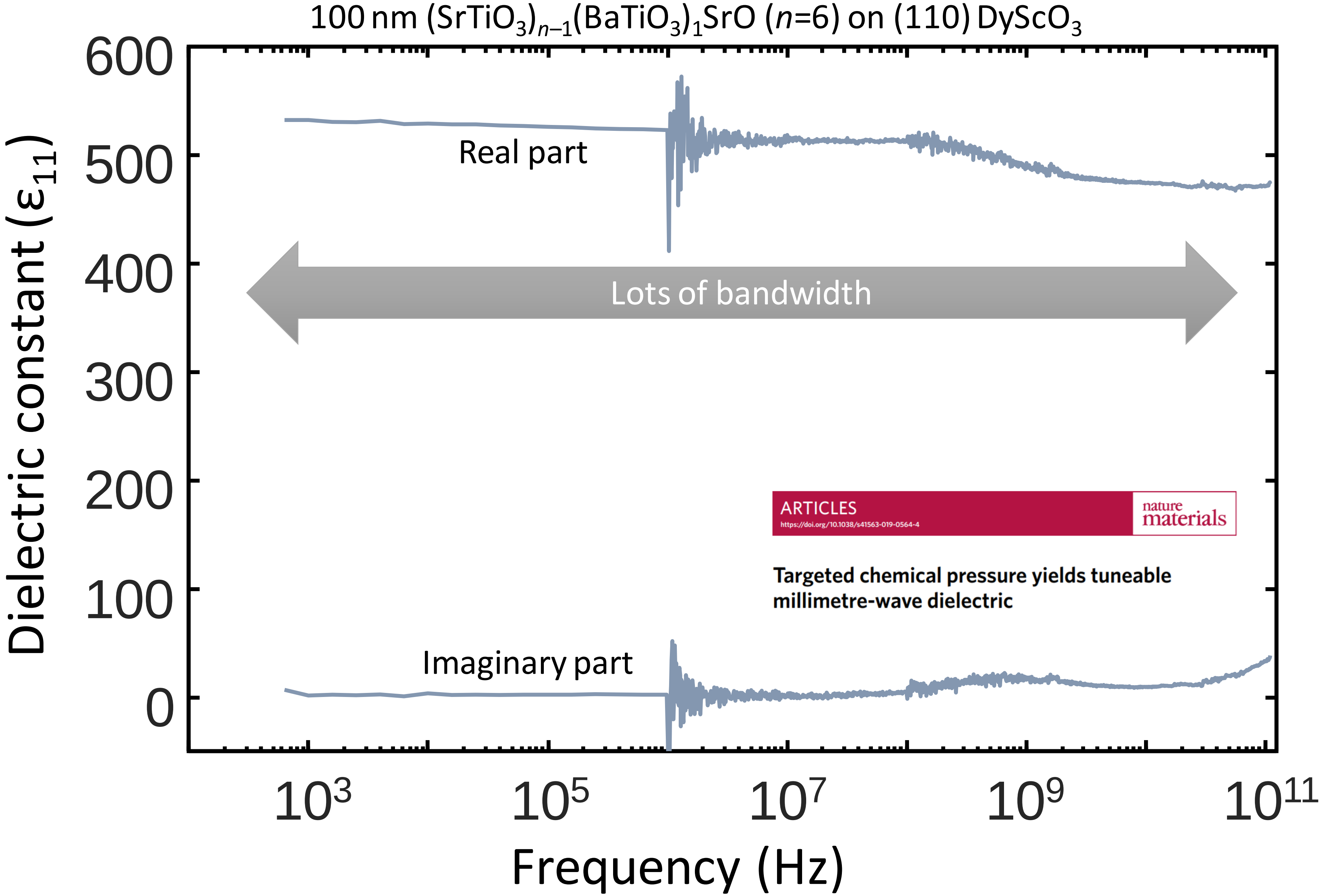
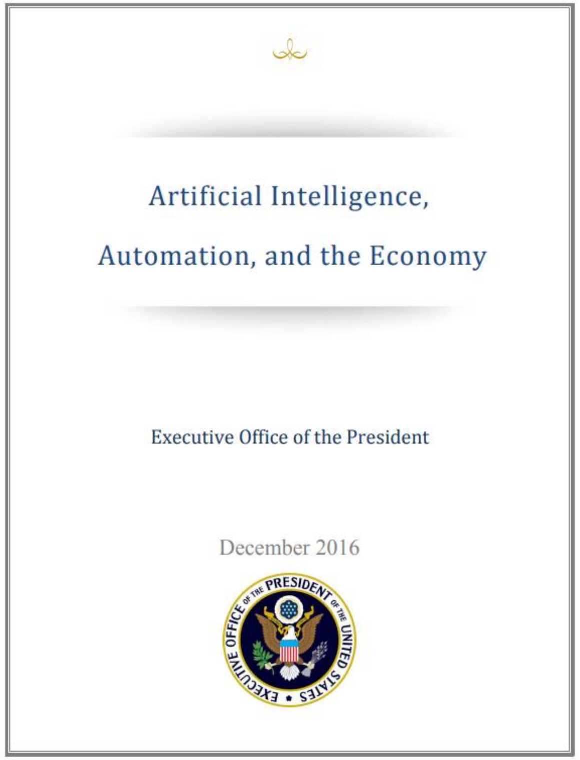
Today's talk is about how we do this…



Eric Marksz

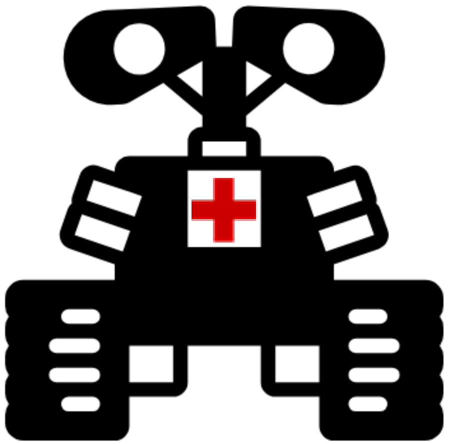
AI and Automation will **change the economy**

We foresaw this…

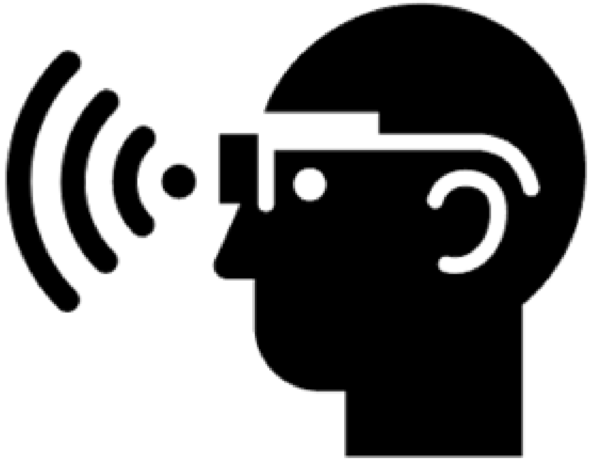

Artificial Intelligence, Automation, and the Economy

Executive Office of the President

December 2016


Automation

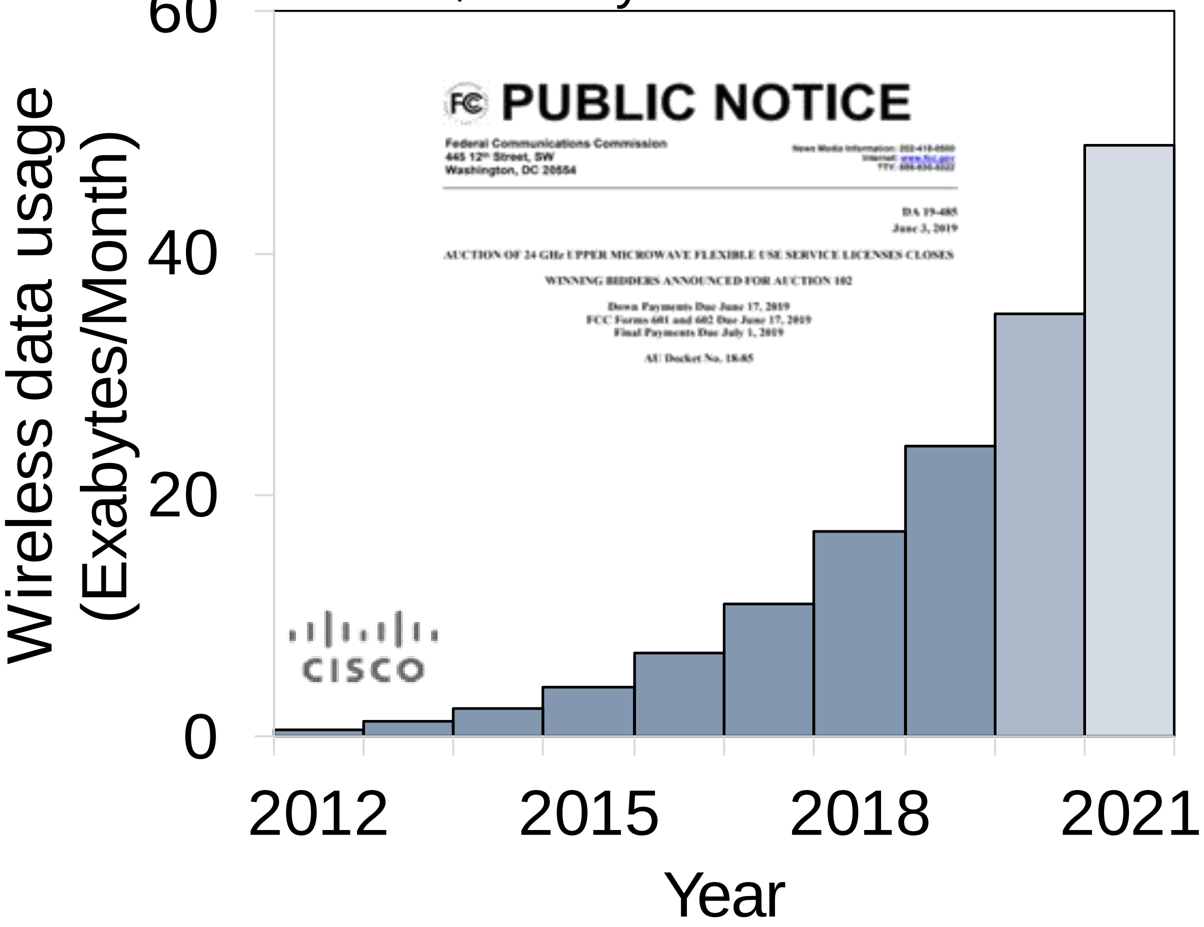

Internet of things


Artificial intelligence

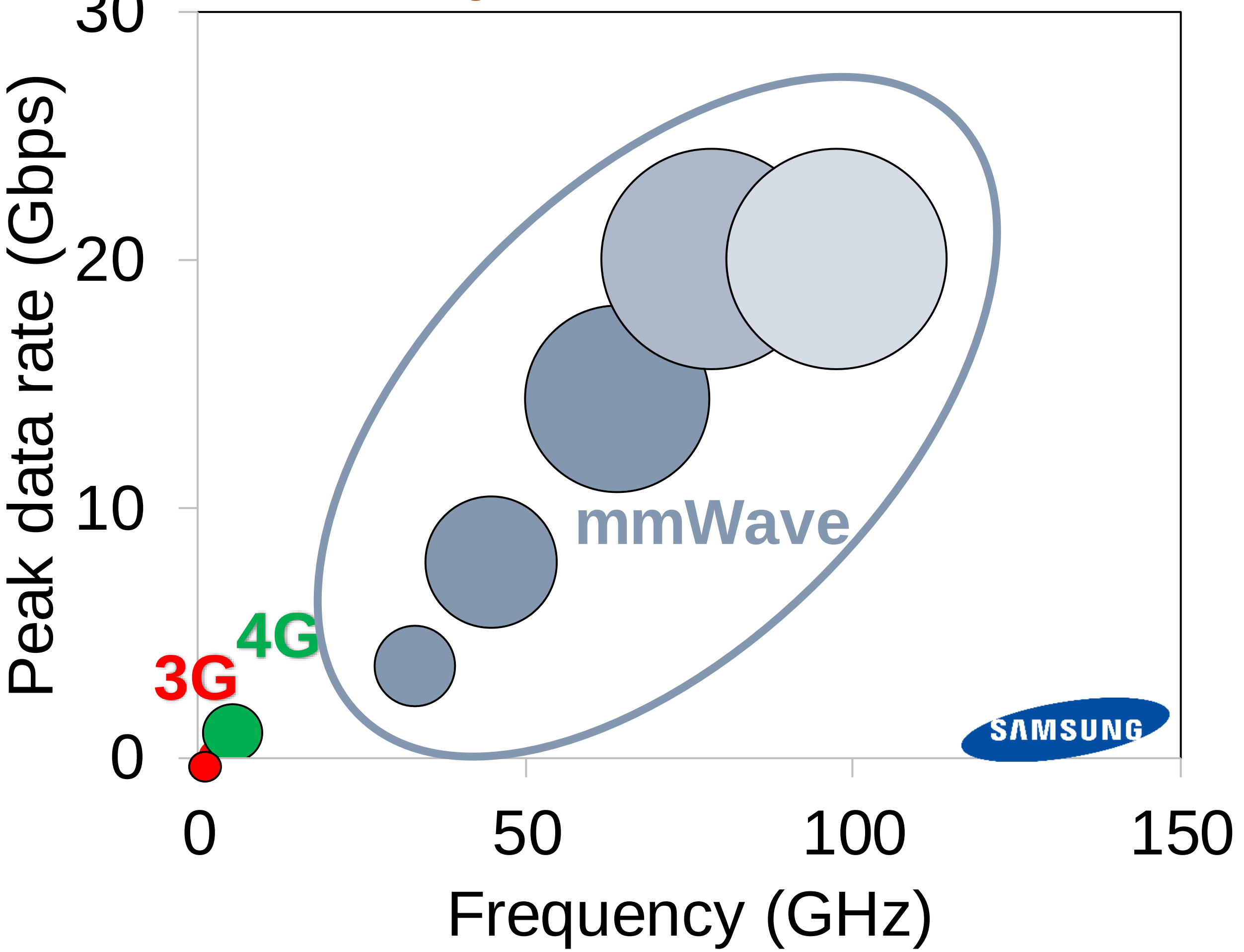
Estimates **47% US jobs** will be impacted by AI and Automation

Low latency, high data communications are key

$600B/y and 2.7M Jobs



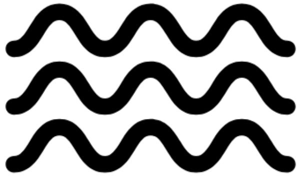
32% of global semiconductor market



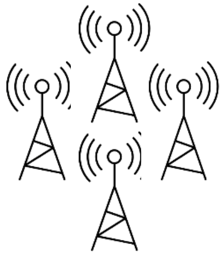
mmWaves will be enabling technology that makes all this happen

mmWaves aren't the only new thing in 5G

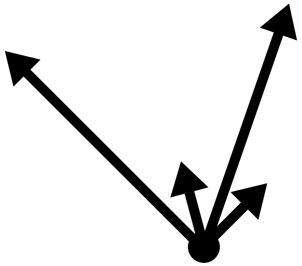
Current release



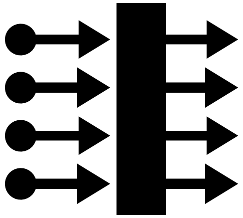
mmWaves



Small cells

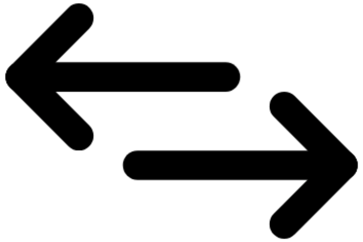


Beam-forming

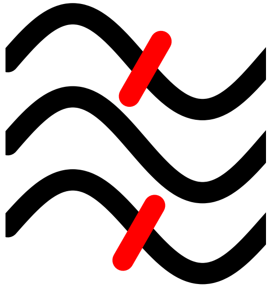


MIMO

Future?



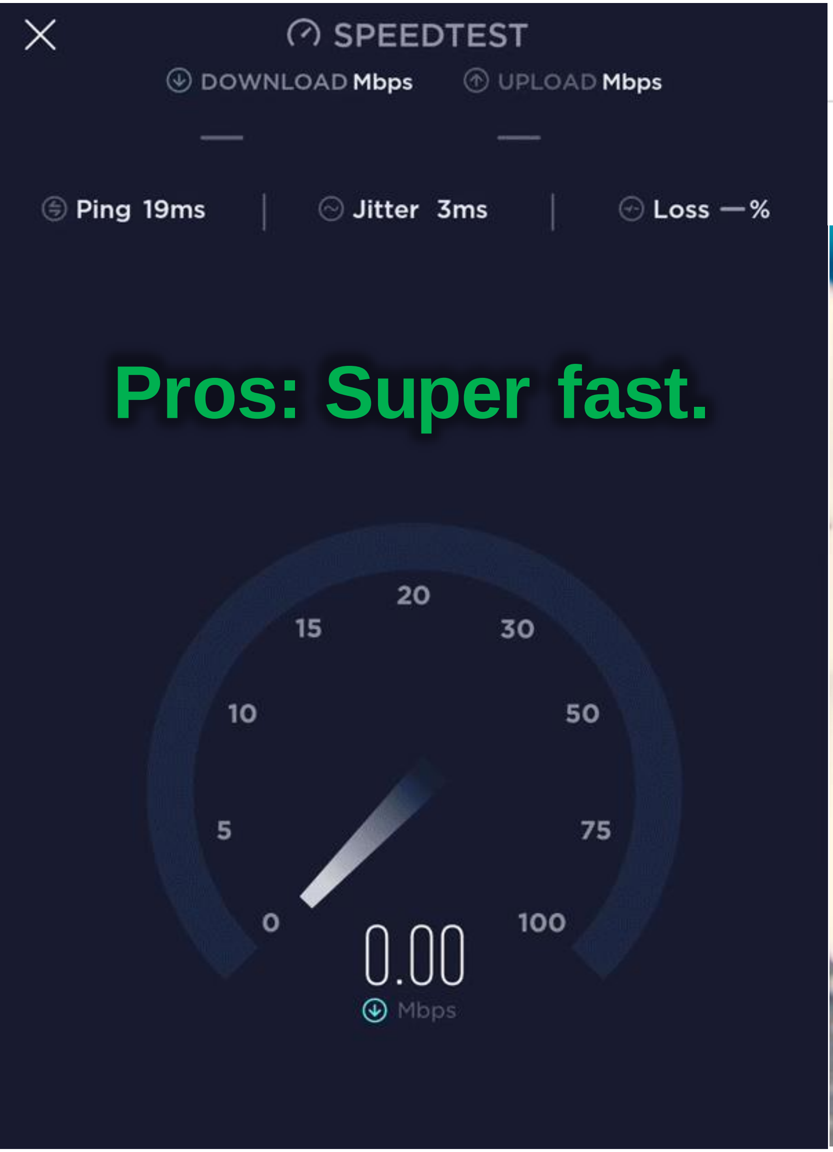
Full duplex



Filters

And that hardware requires testing before it rolls out to consumers

5G handsets **overheat** due to energy efficiency

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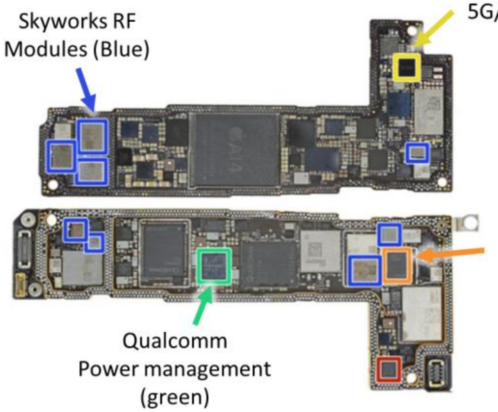
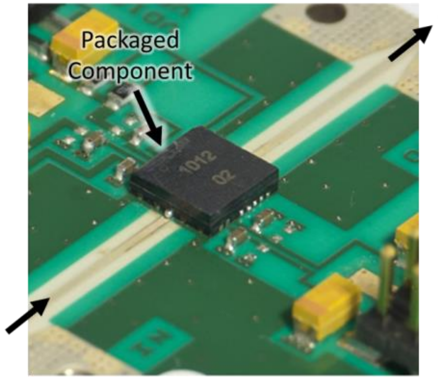
We Tested 5G Across America. It's Crazy Fast—and a Hot Mess

In tests, the 5G often switched off due to summer heat, leaving our columnist to cool the devices with ice packs or air conditioners

Why are the phones overheating?

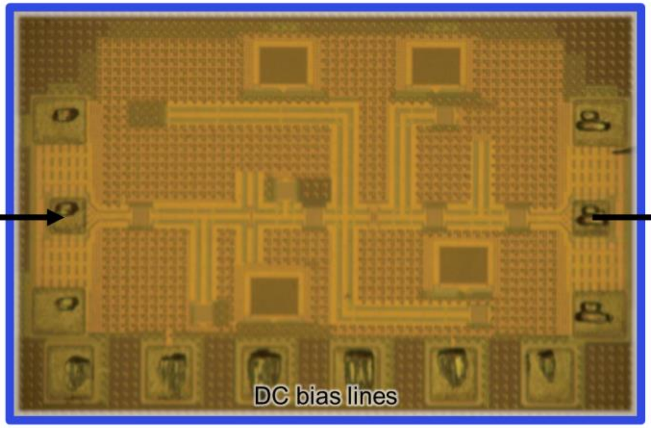
iPhone 12





Credit: Liam Devlin, CEO, Plextek RFI

Heydari, et al. IEEE CICC, 2007. pp. 769-772.

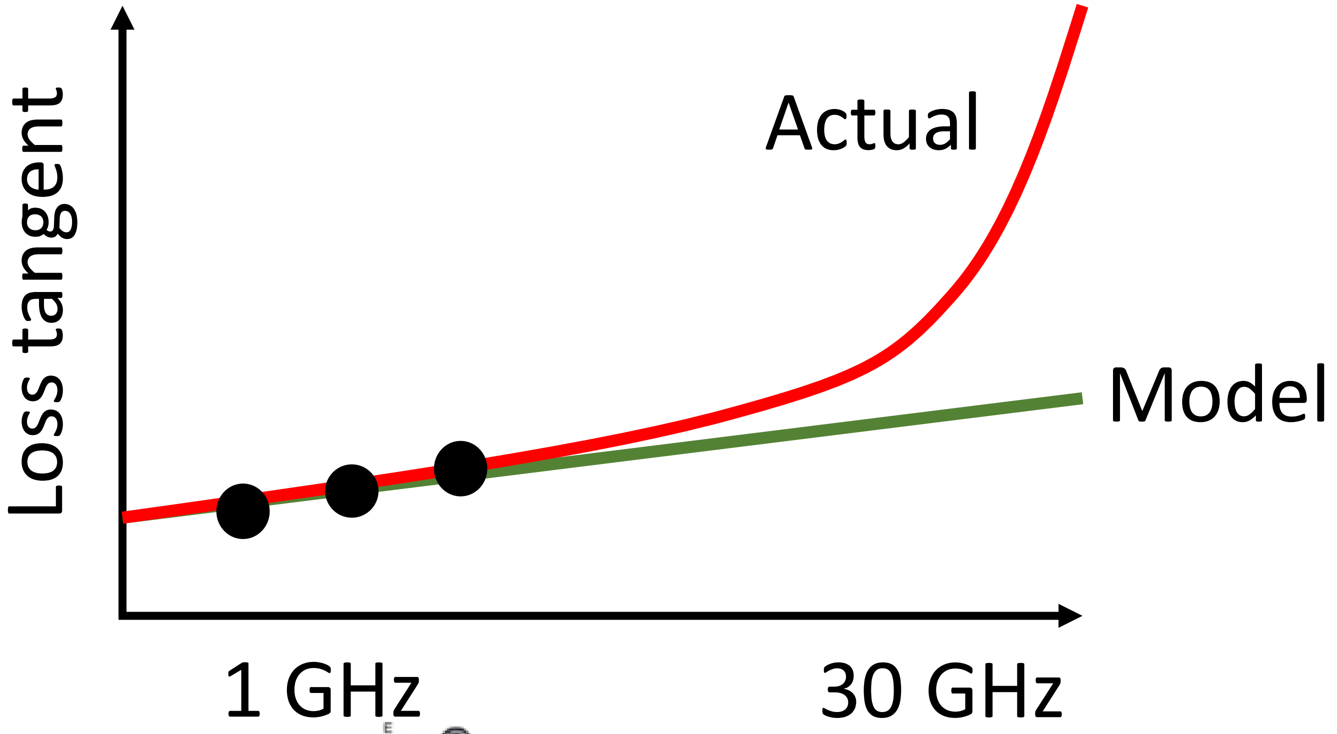


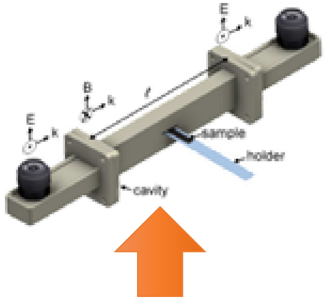
*Figures here are for illustration of the idea and are not used in phones or the reason deployed phones overheat

One potential problem is with the materials

This is a random phone

?



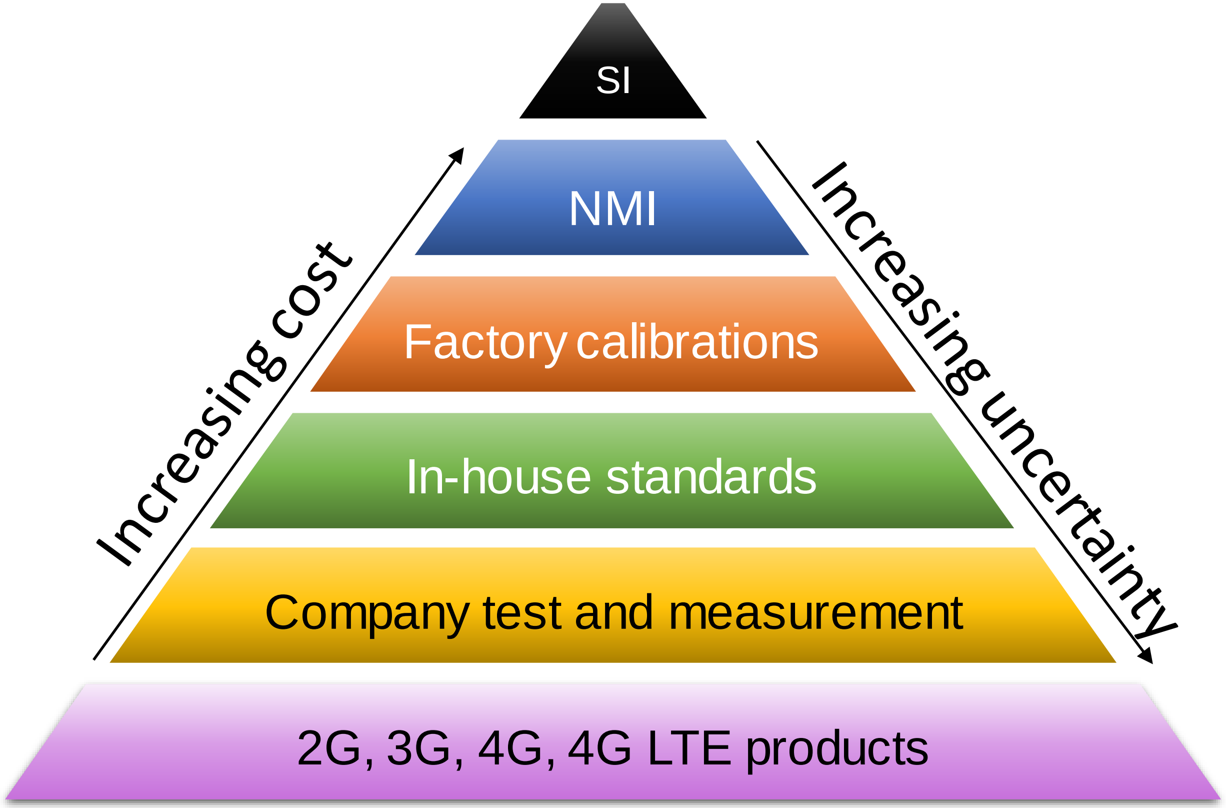


Vendor measures here

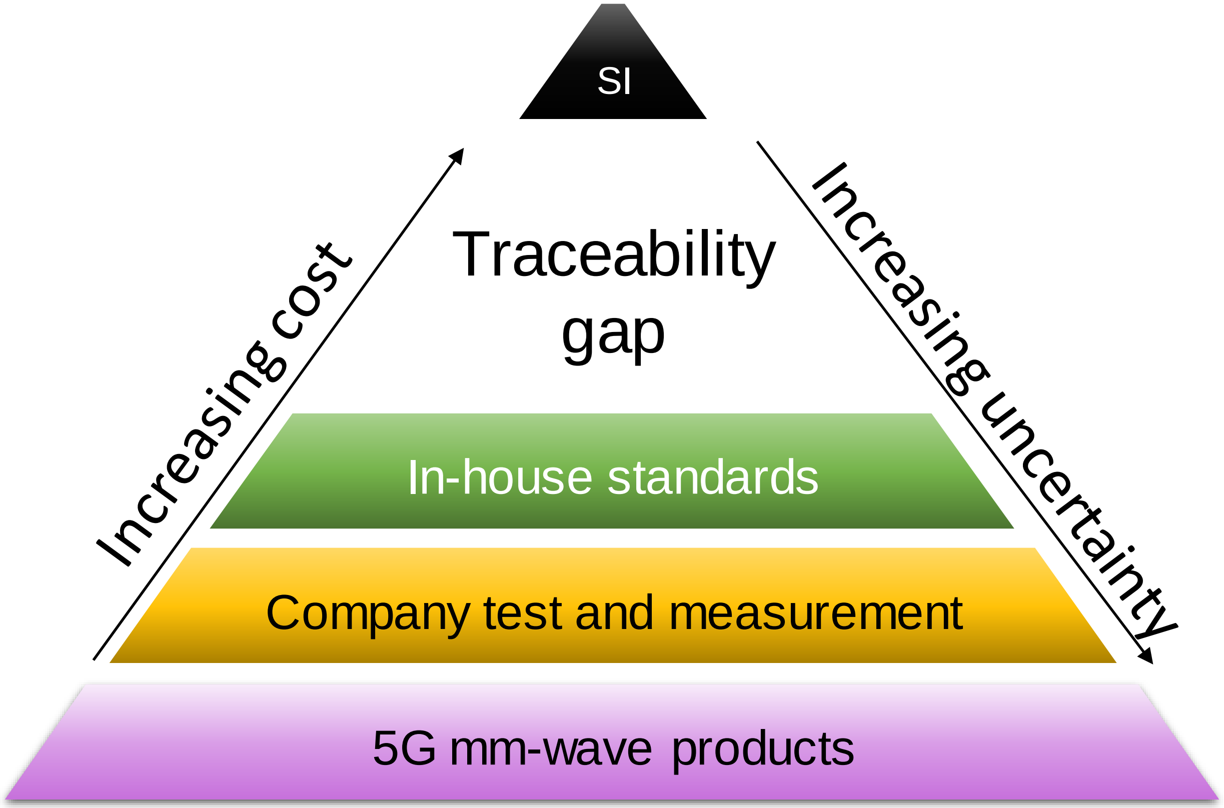
5G works here

How do we know we are right?

Permittivity traceability for current technology

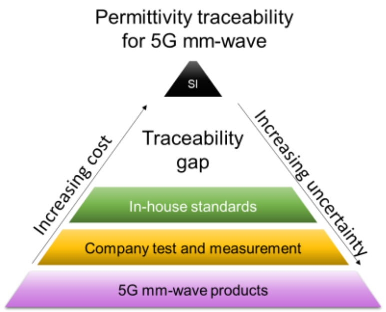


Permittivity traceability for 5G mmWave

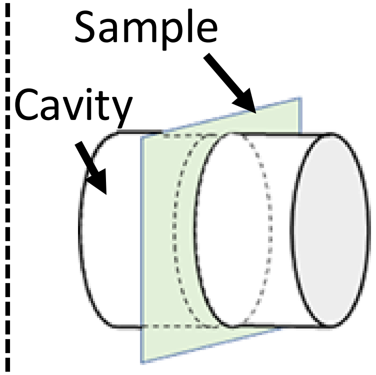


How can we fill the mmWave traceability gap?

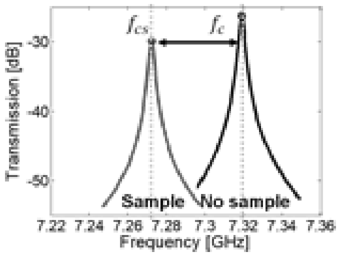
mmWave traceability gap



1 Dimension sample and Cavity

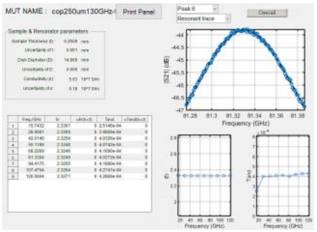


2 Measure S-parameters



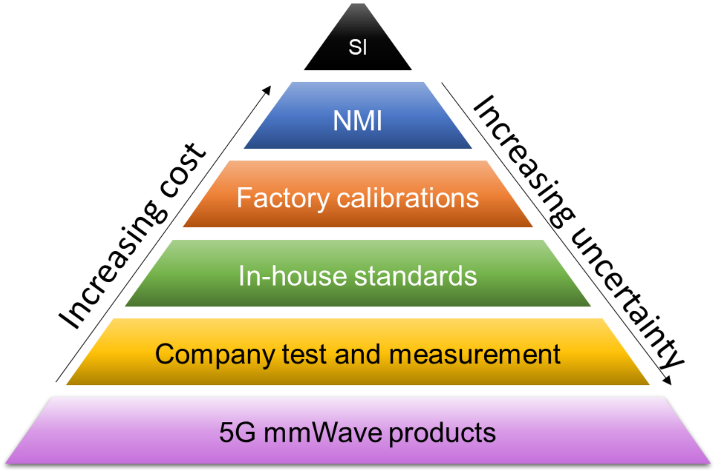
3 Map to permittivity

$$\epsilon_{r_s} \approx \left(\frac{V_c}{2V_s}\right)\left(\frac{\omega_c-\omega_{cs}}{\omega_c}\right)+1$$



4 Gap filled… But we aren't done…

Permittivity traceability for 5G mmWave

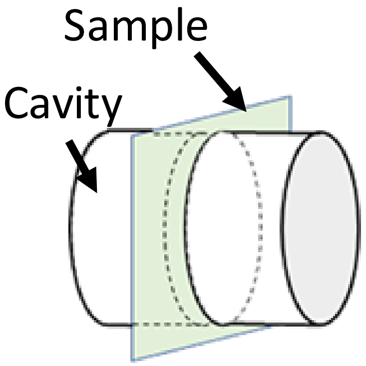


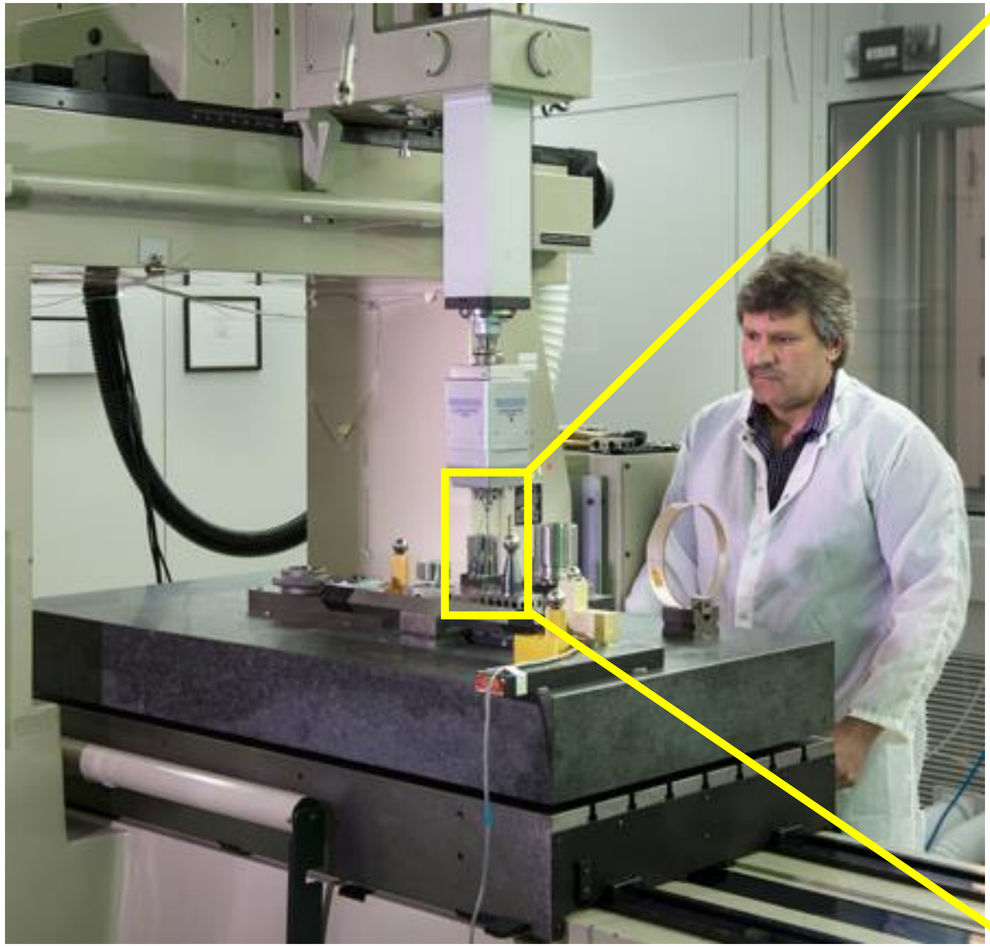
Just making a Standard Reference Material is not enough

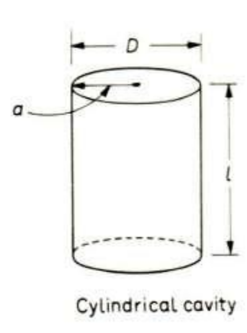
International Microelectronics Assembly & Packaging Society

So how can we get traceability?

1 Dimension sample and Cavity



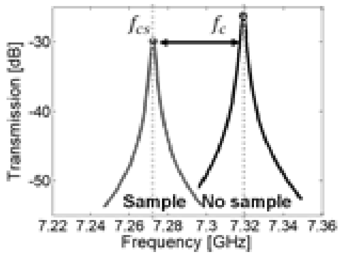




We need the dimensions of the cavity and the sample

We also need the S-parameters

2 Measure S-parameters



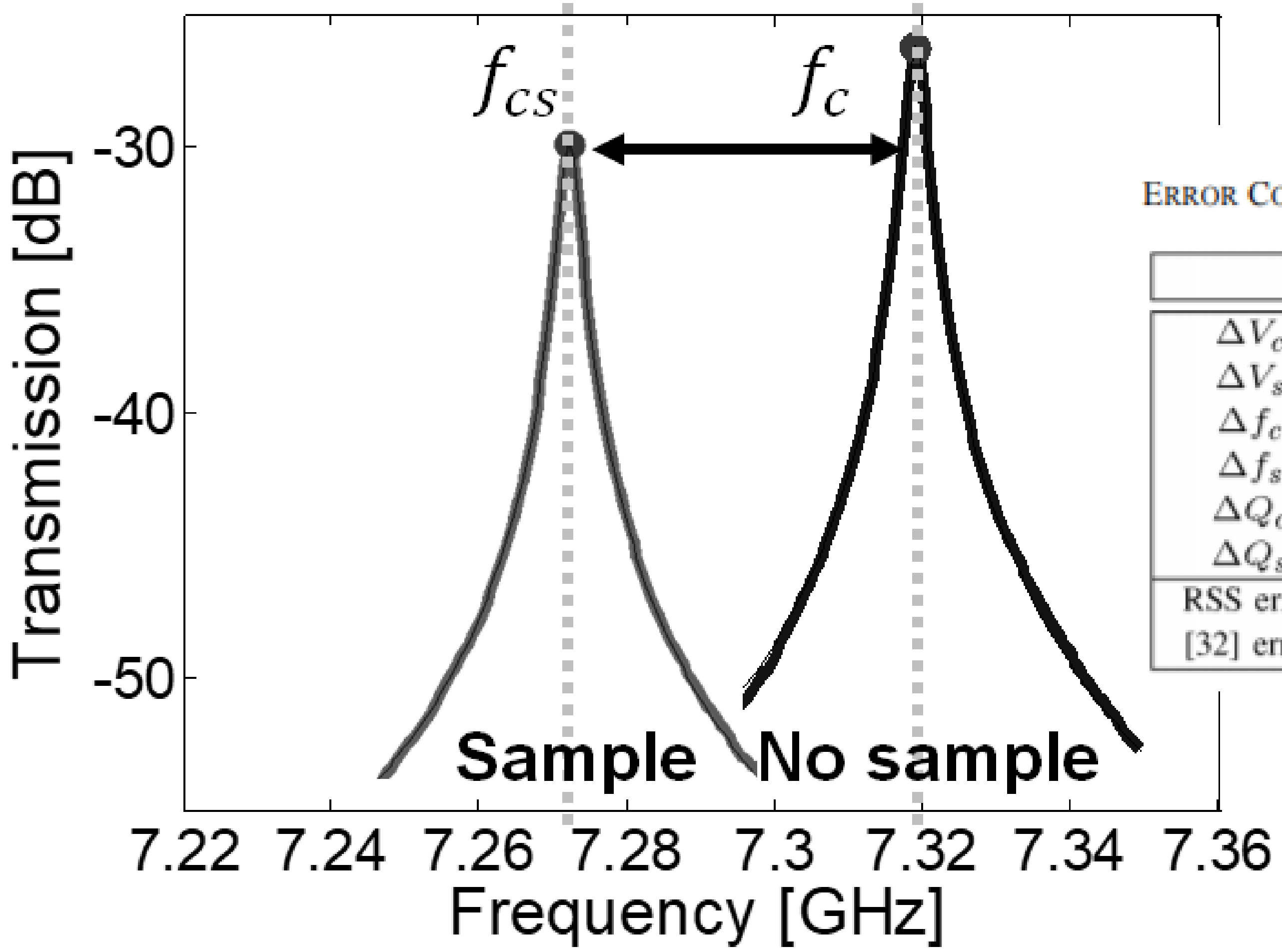


TABLE I
ERROR CONTRIBUTIONS FOR THE QUARTZ SAMPLE

	Value	$\Delta\epsilon_r$	$\Delta\epsilon_i$
ΔV_c	50.7 mm^3	0.004	~0
ΔV_s	0.2 mm^3	0.086	~0
Δf_c	5.4 kHz	0.001	—
Δf_s	5.2 kHz	0.001	—
ΔQ_c	6.8	—	0.001
ΔQ_s	6.8	—	0.001
RSS error	—	0.09	0.002
[32] error	—	0.06	0.002

Goodness of fit estimates uncertainties in resonance frequency and losses

What is a on-wafer calibration kit

Permittivity traceability for 5G mmWave

TABLE I
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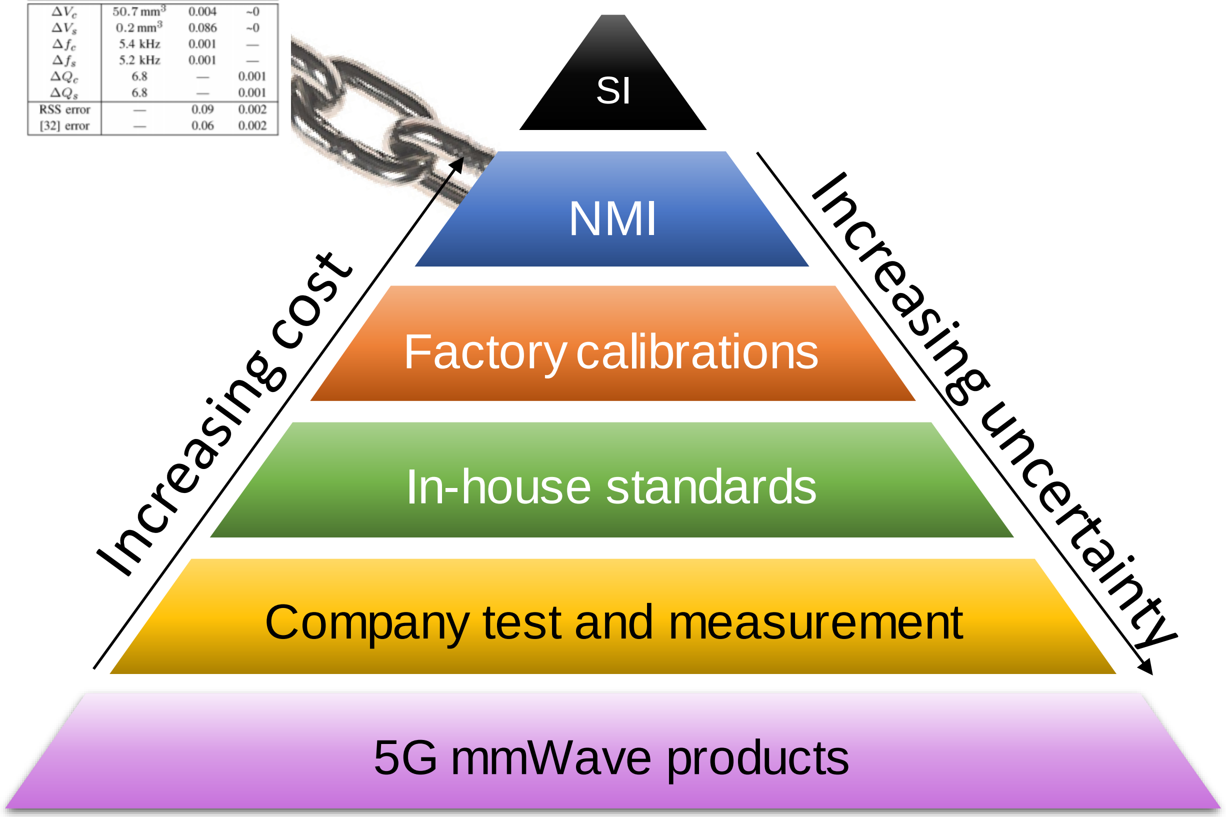
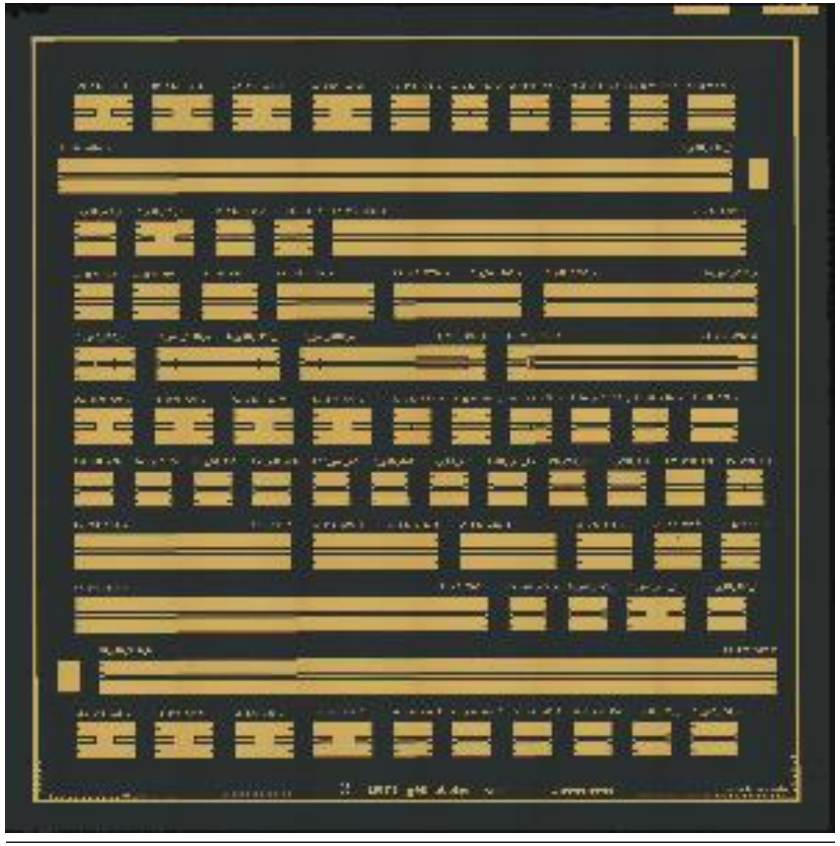


On-wafer traceability for 5G mmWave



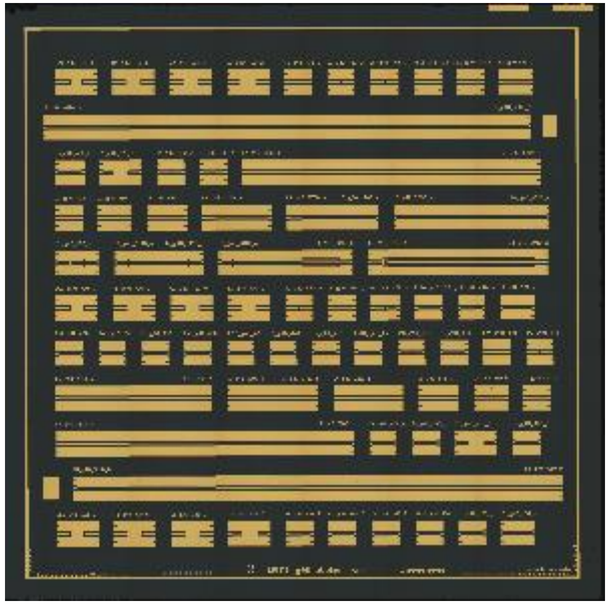
1 cm

This on-wafer kit makes your measurements traceable and so much more

On-wafer traceability lets you calibrate devices

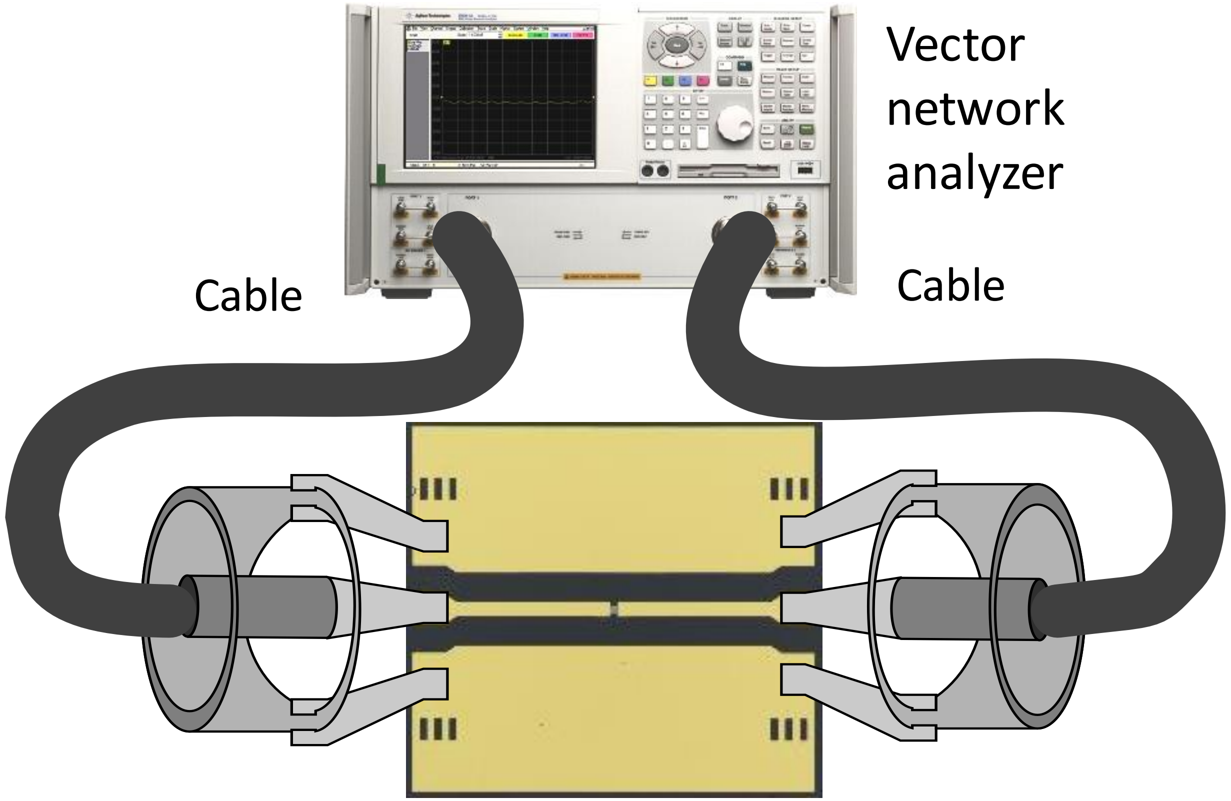
*technically data correction

1 Reference wafer



1 cm

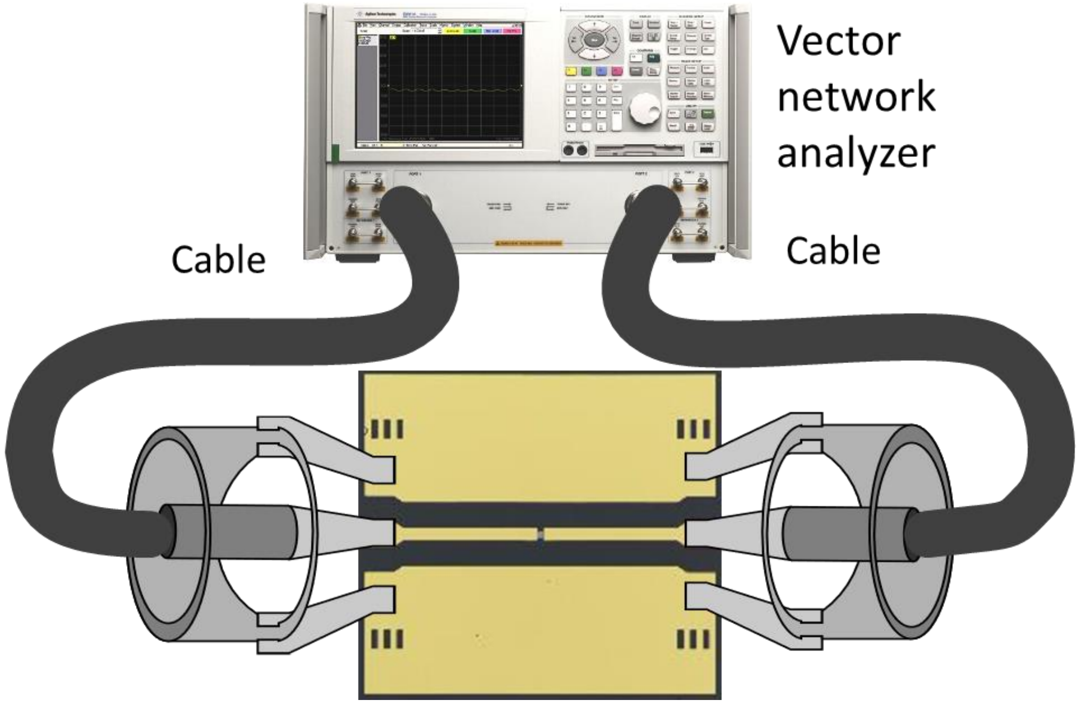
On-wafer measurement

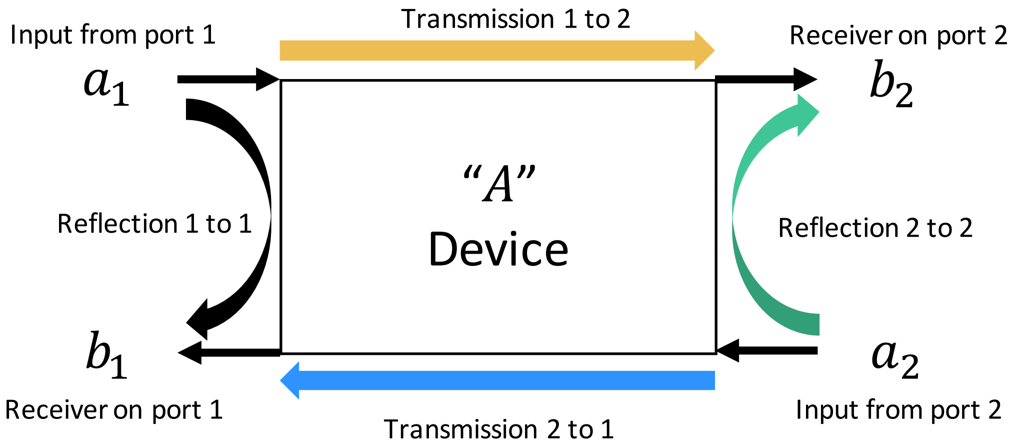


Without calibrations, our data is nearly useless

A VNA measures **S-parameters**

On-wafer measurement



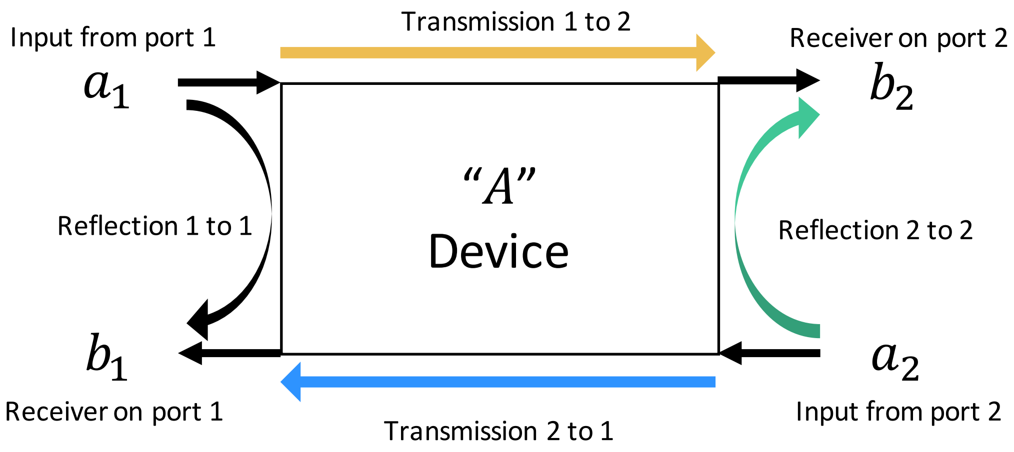


$$S = \begin{pmatrix} Reflection\ 1\ to\ 1 & Transmission\ 2\ to\ 1 \\ Transmission\ 1\ to\ 2 & Reflection\ 2\ to\ 2 \end{pmatrix}$$

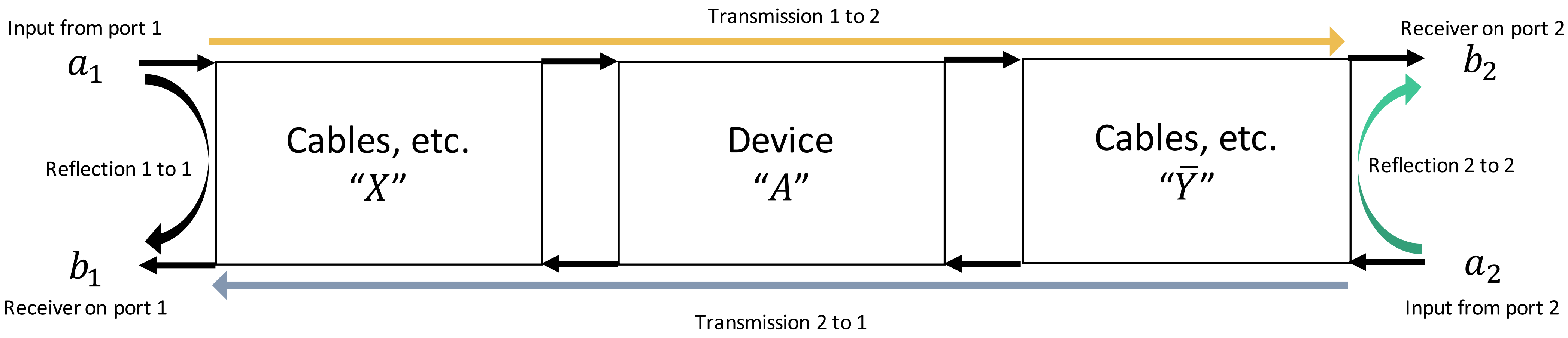
They relate input voltages (‘a’) to output voltages (‘b’)

So this calibration kit solves a big problem

We don't *actually* measure "A"…

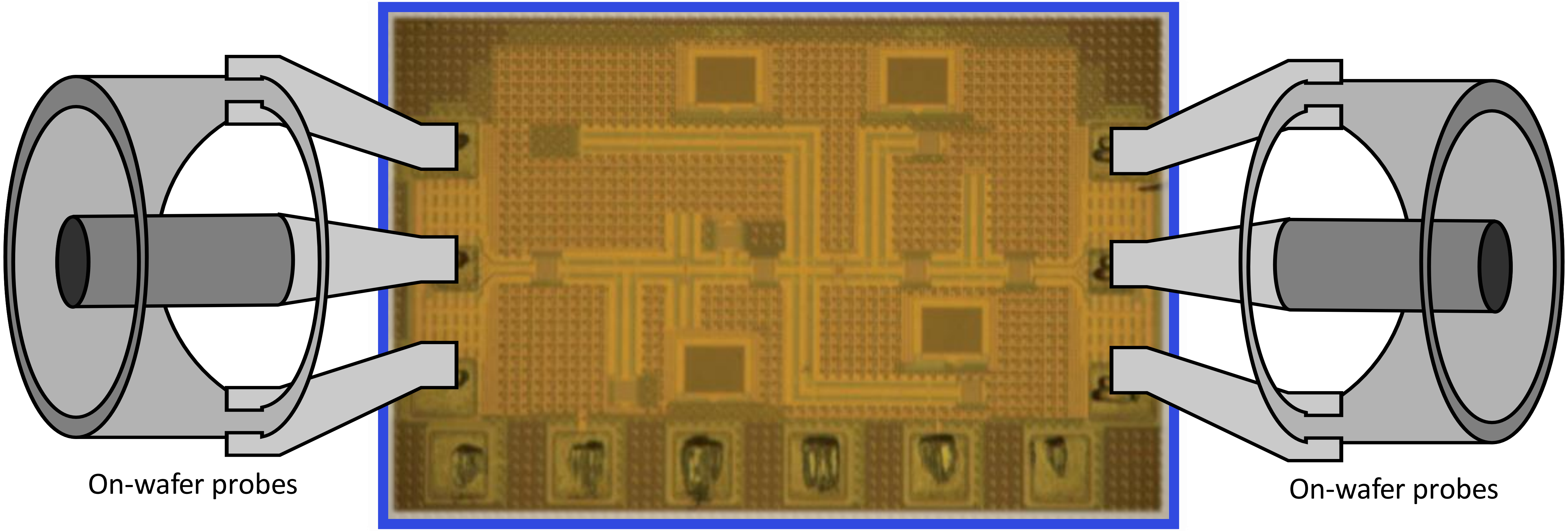


We measure "M"…



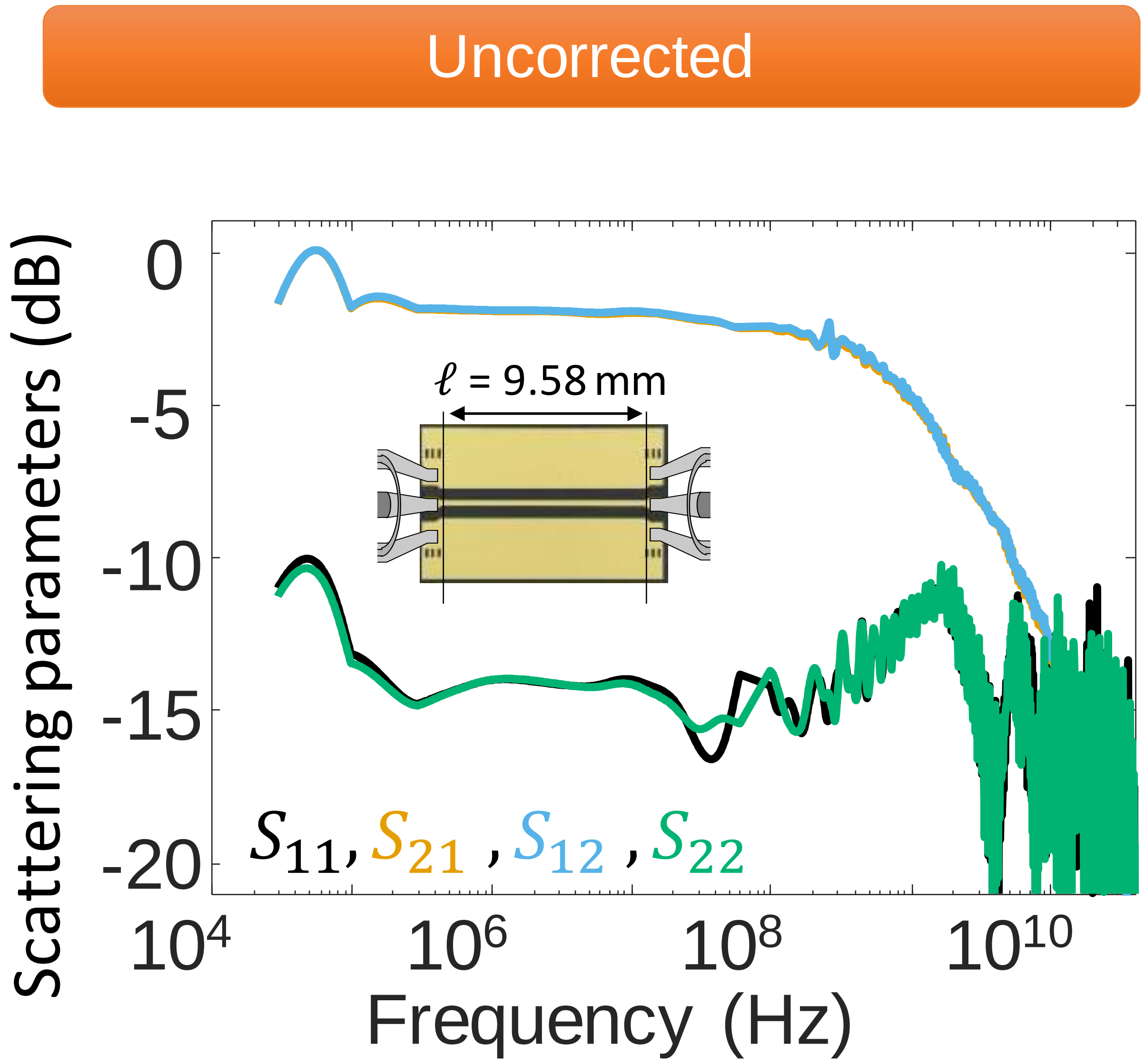
Let’s go back and contact our circuit with probes

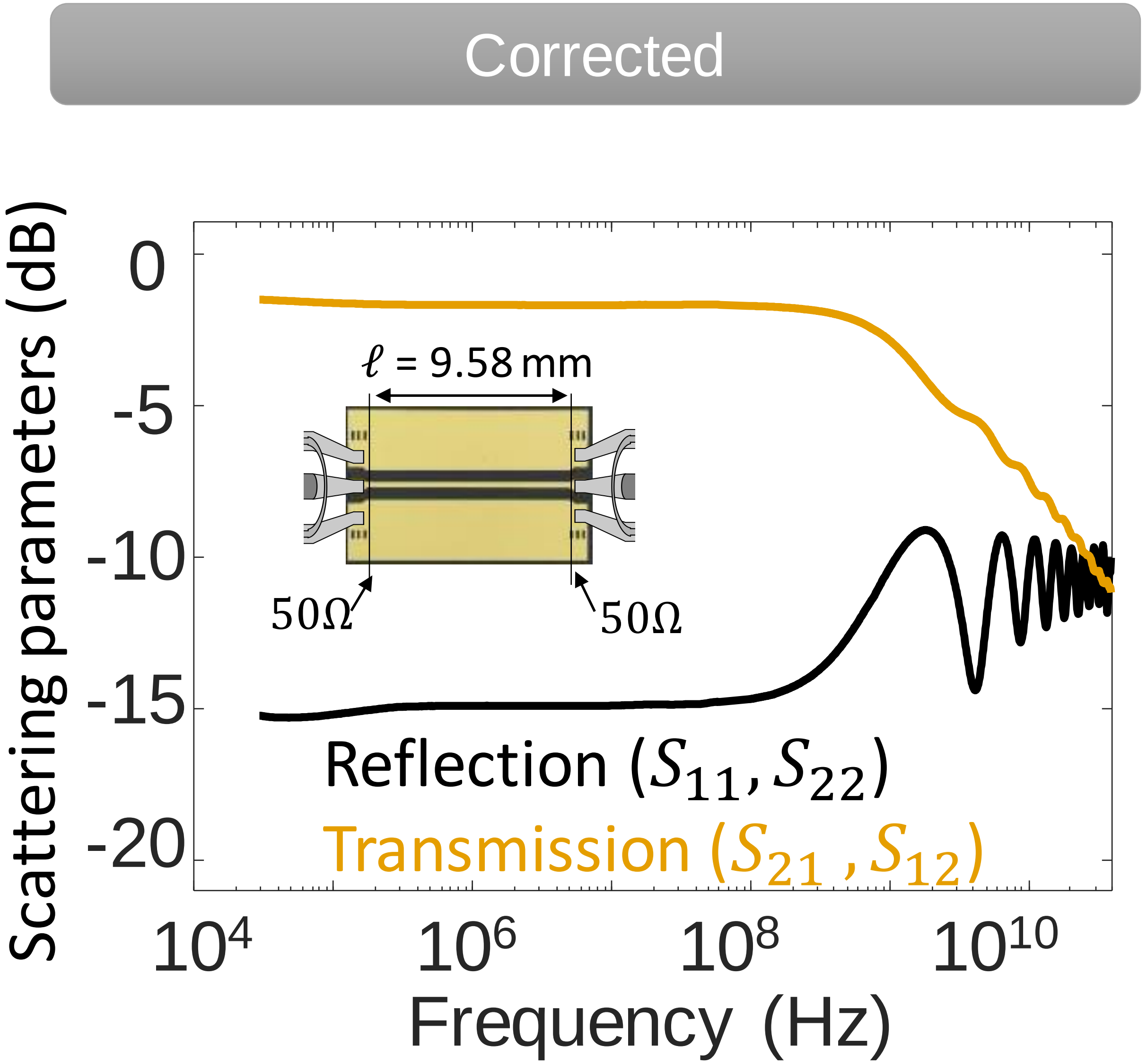
Heydari, et al. IEEE CICC, 2007. pp. 769-772.



Then we can calibrate its S-parameters

Here is what calibrating data means…





Beyond calibrating data...

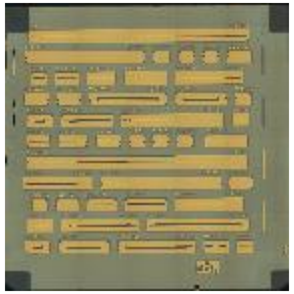
1 Reference wafer

Reference

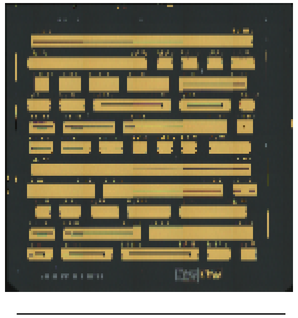
1 cm

2 Substrate and film

Film

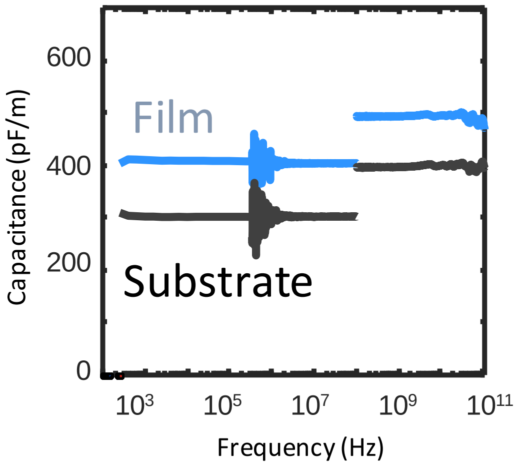


Substrate

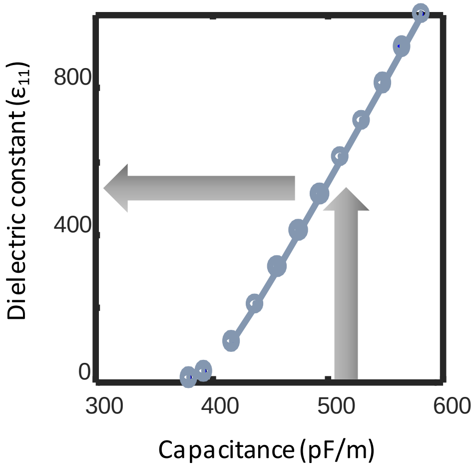


1 cm

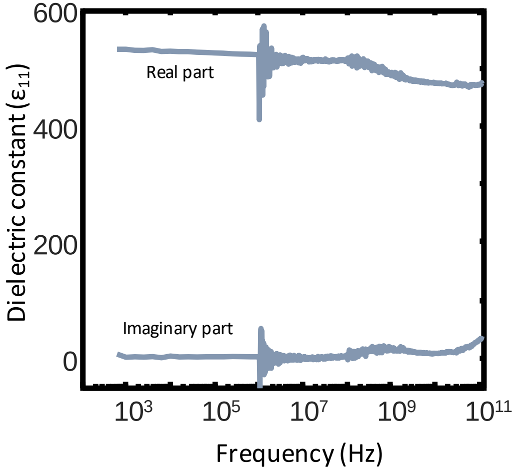
3 Extract circuit parameters



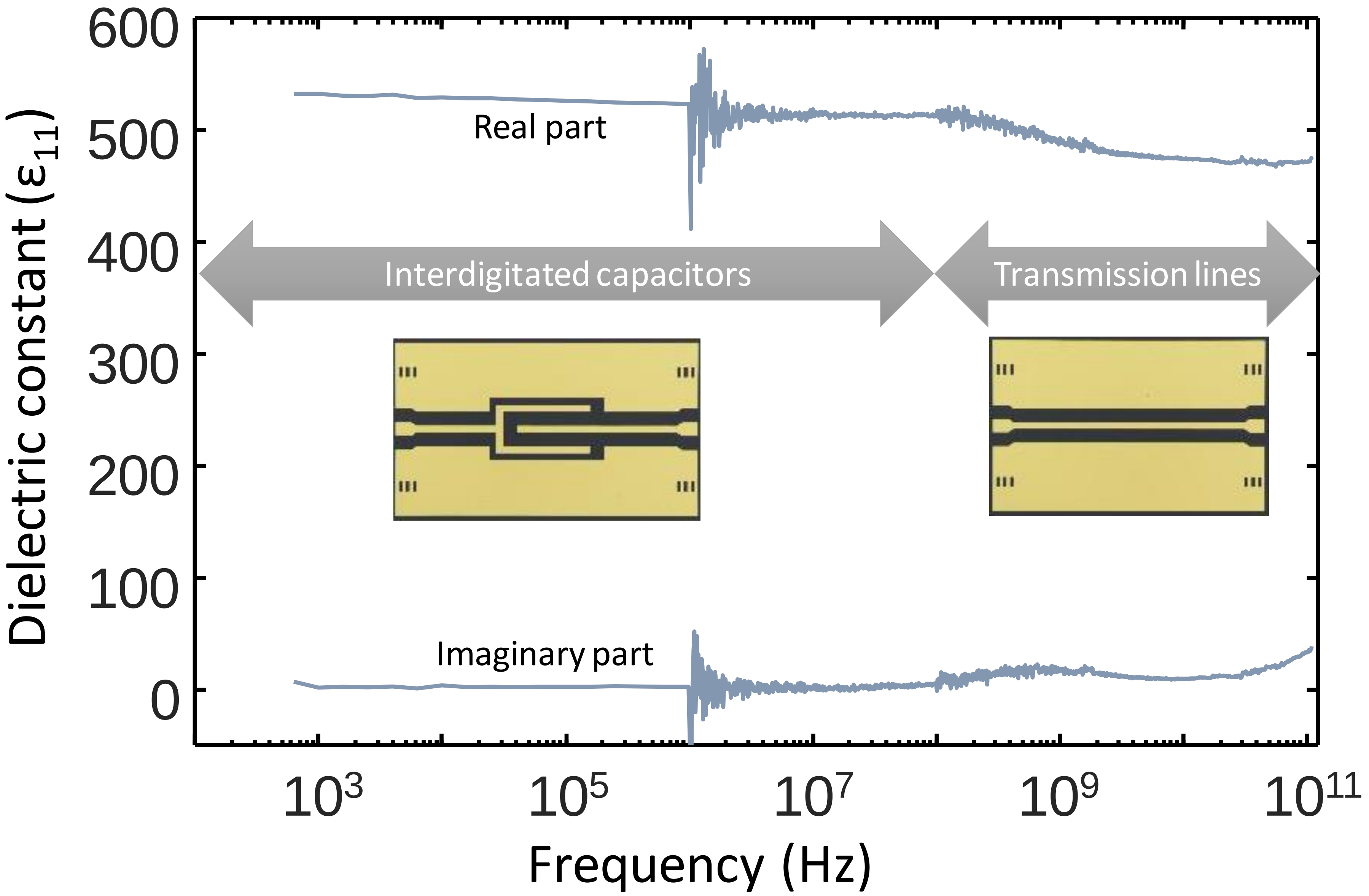
4 Finite-element simulations



5 Map to dielectric constant



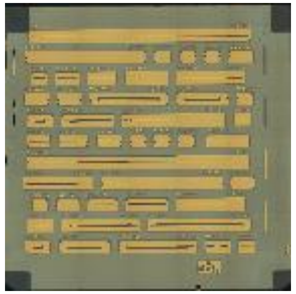
Our end goal is the dielectric constant



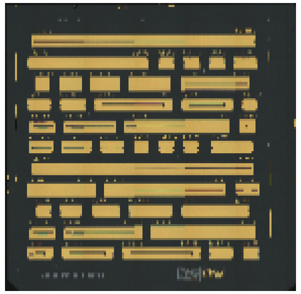
We break the regimes up by devices…

2 Substrate and film

Film

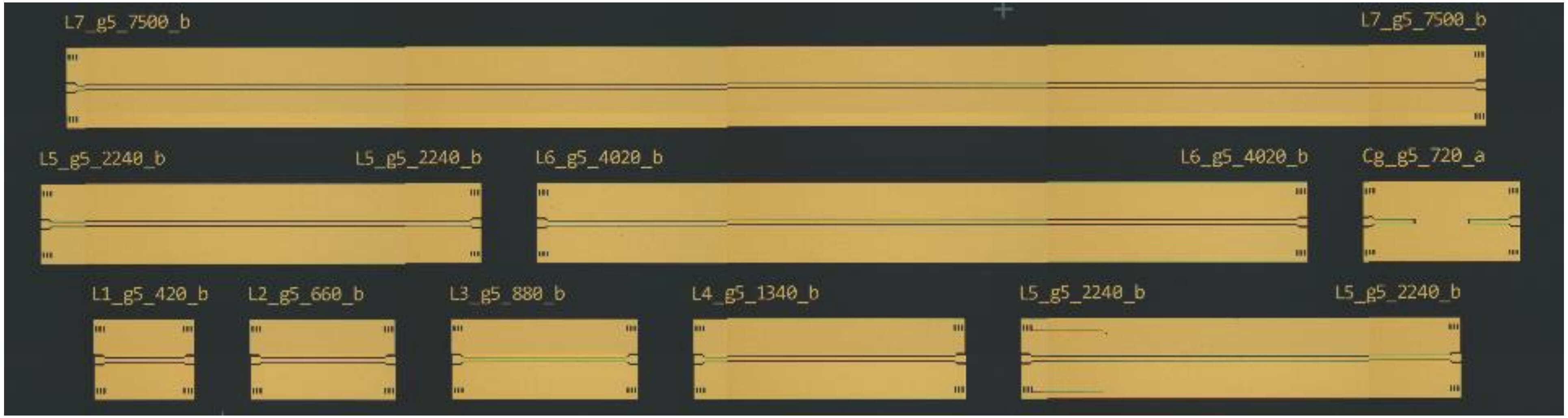


Substrate



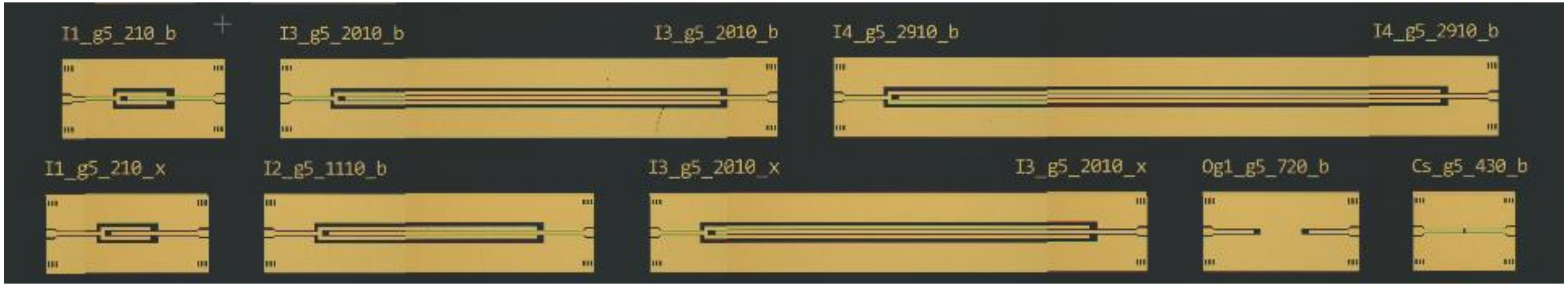
1 cm

- High frequency



0.5 cm

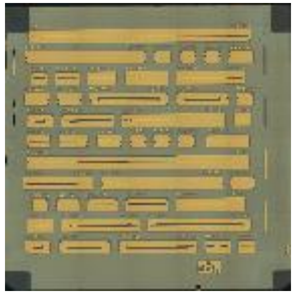
- Radio frequency & Low frequency



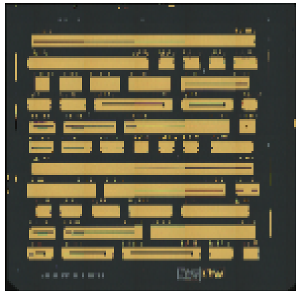
What is a coplanar waveguide (CPW)?

2 Substrate and film

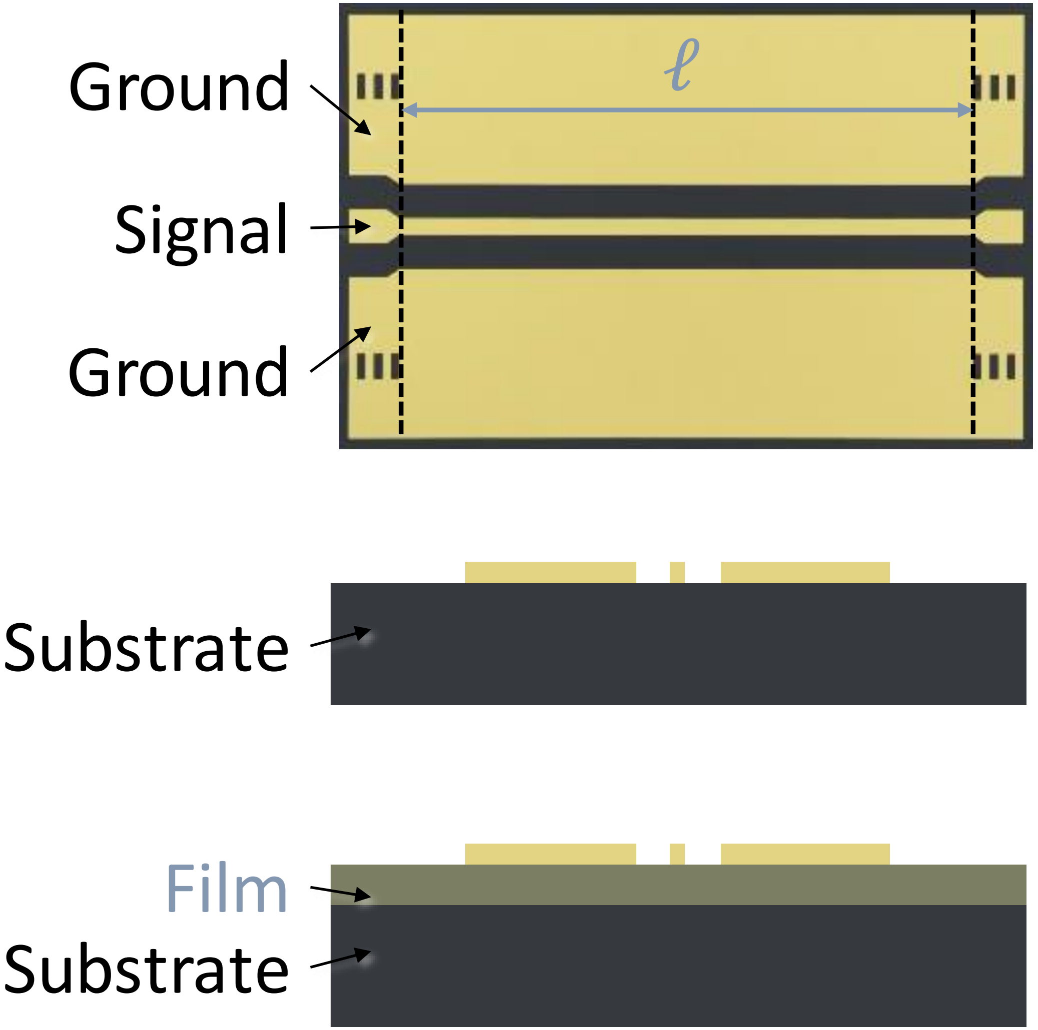
Film

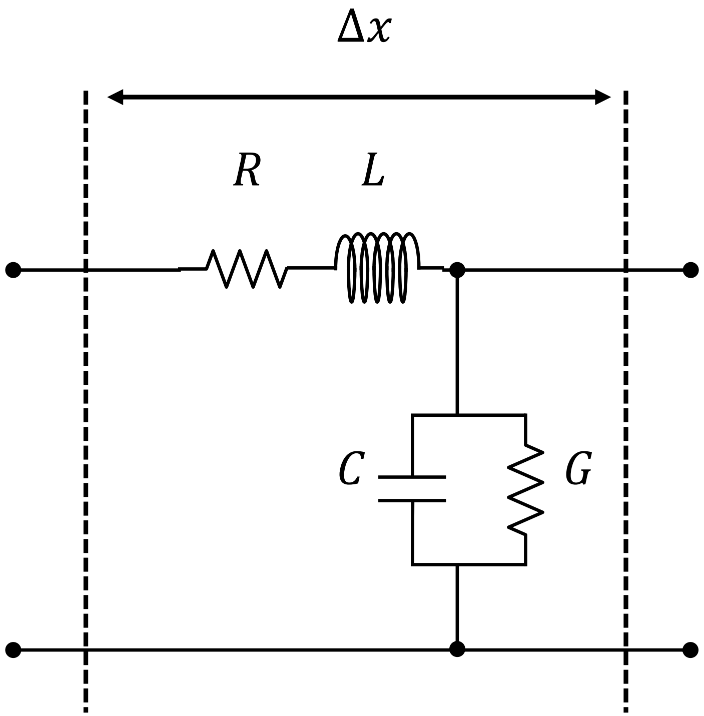


Substrate



1 cm

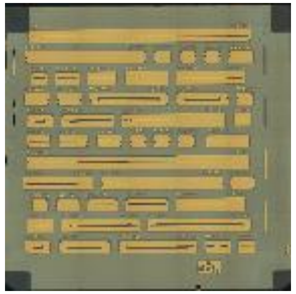




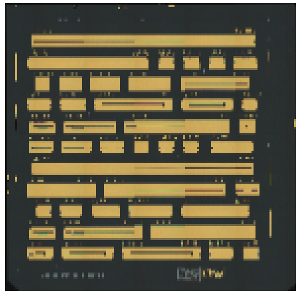
CPWs: what does the electric field look like?

2 Substrate and film

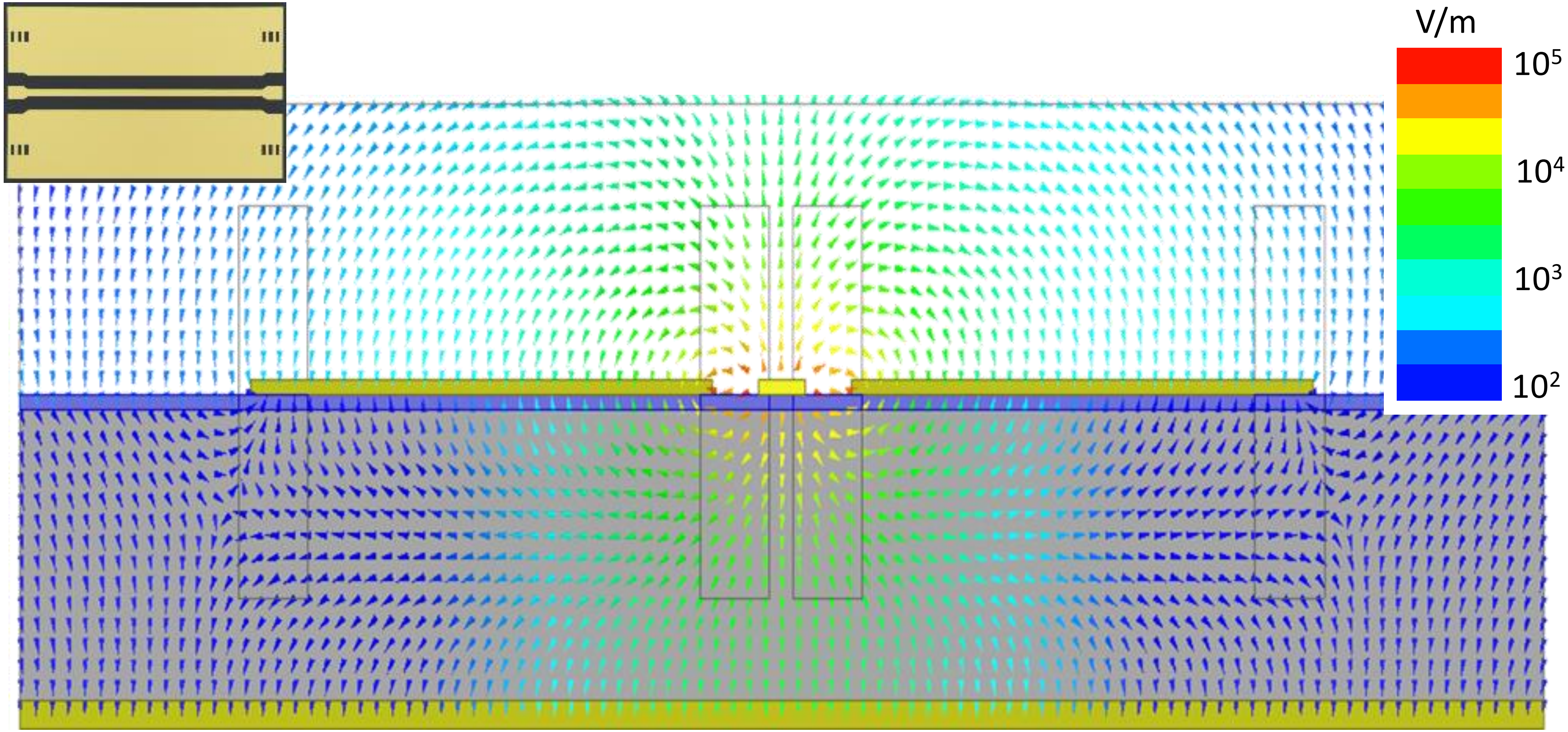
Film



Substrate



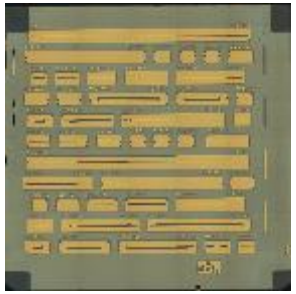
1 cm



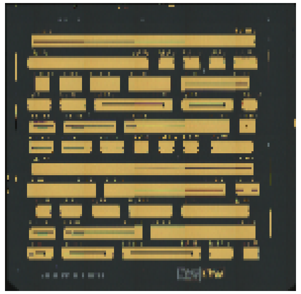
Here is what we get for our film

2 Substrate and film

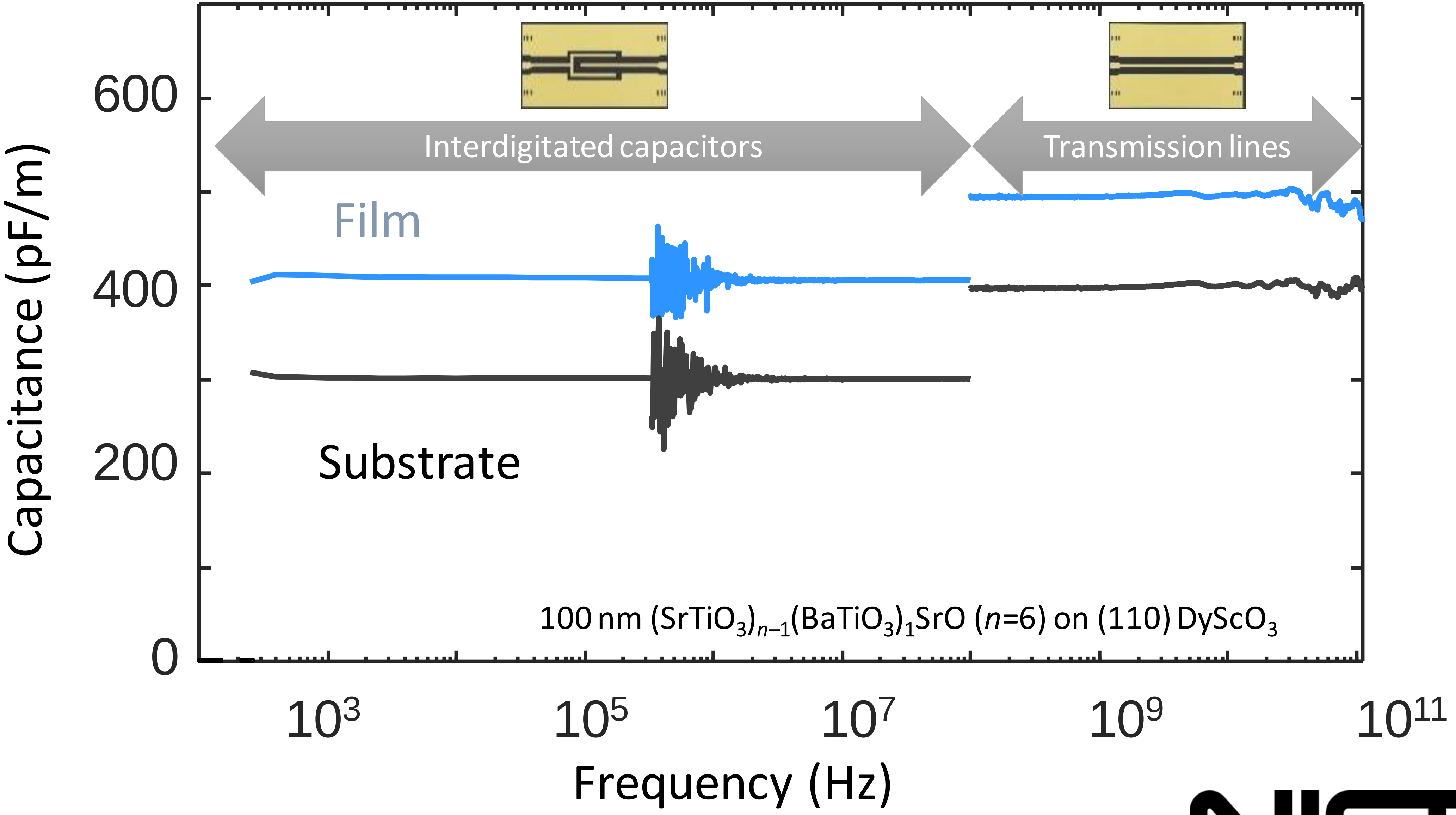
Film



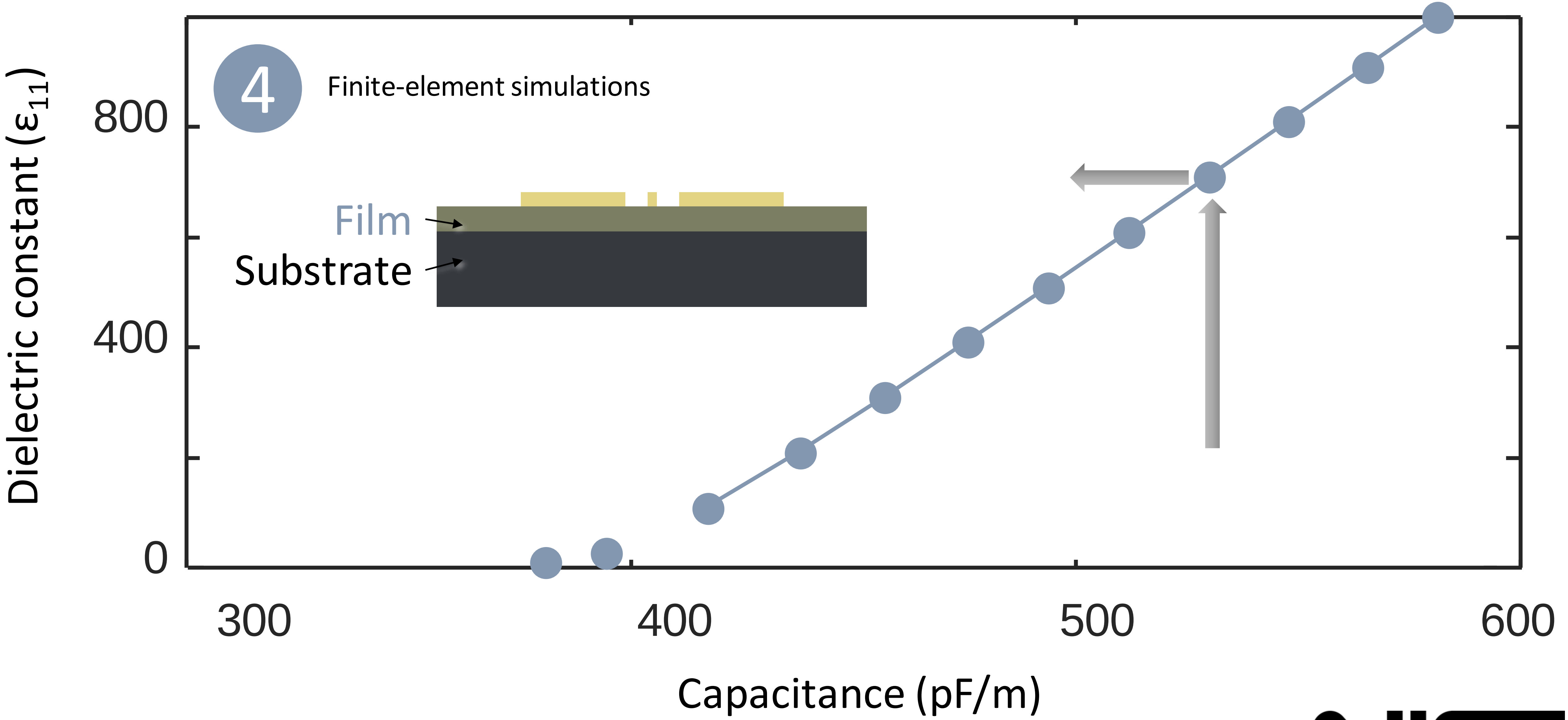
Substrate



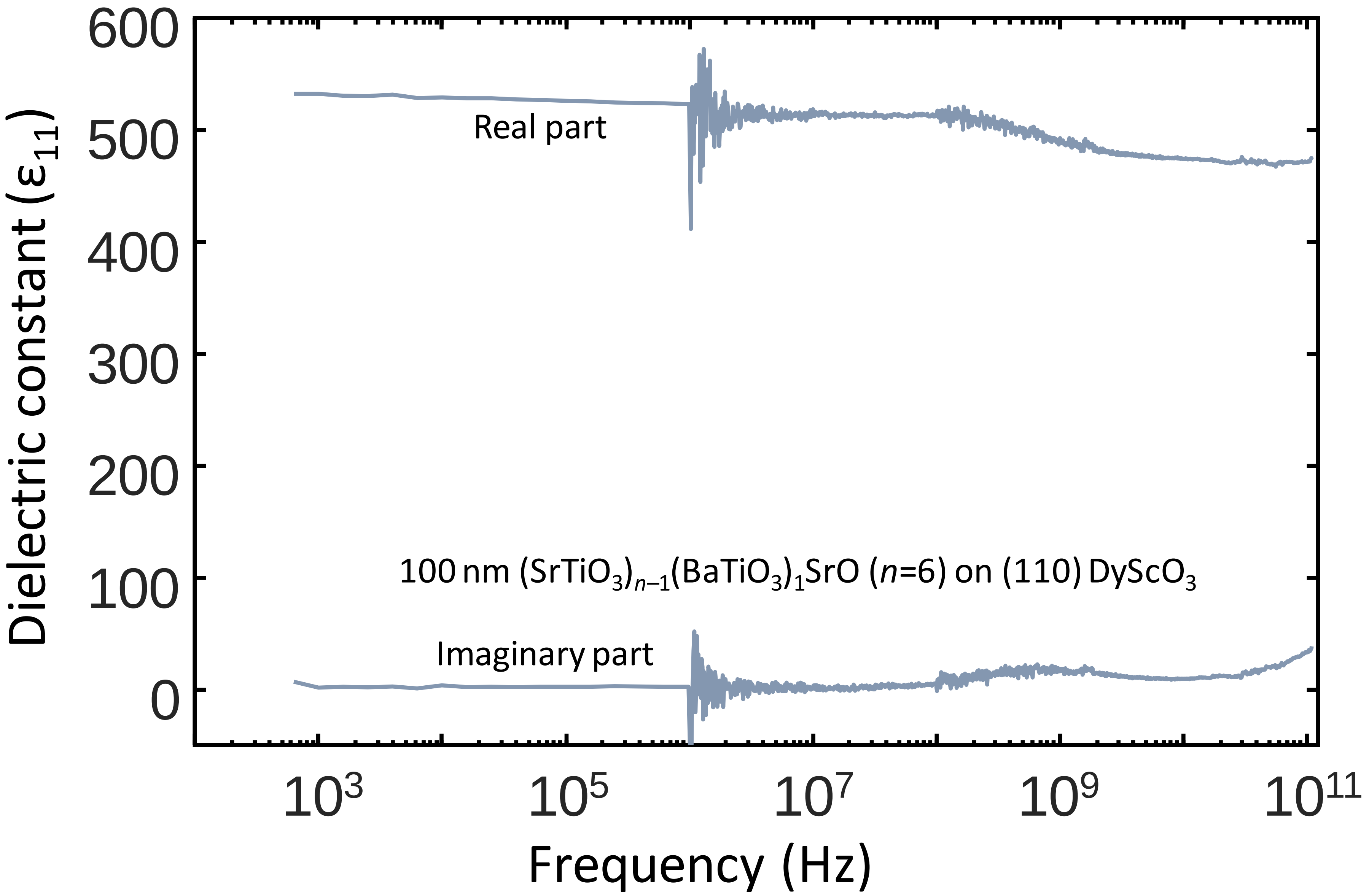
1 cm



Next, we simulate the cross section



And here is the result for this film…

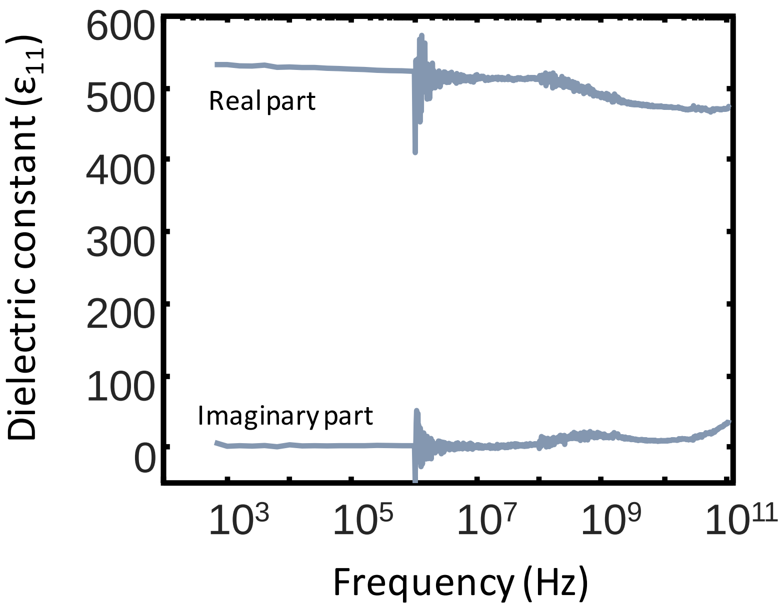


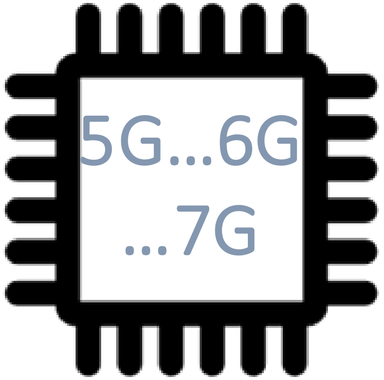
5G is here… and **you** can help.

Better materials measurements and models

Analog and digital devices

New markets and more capacity





Thanks.