RF Channel Emulation and Practical Considerations for Lab Testing at mmWave Bands with Real Devices.

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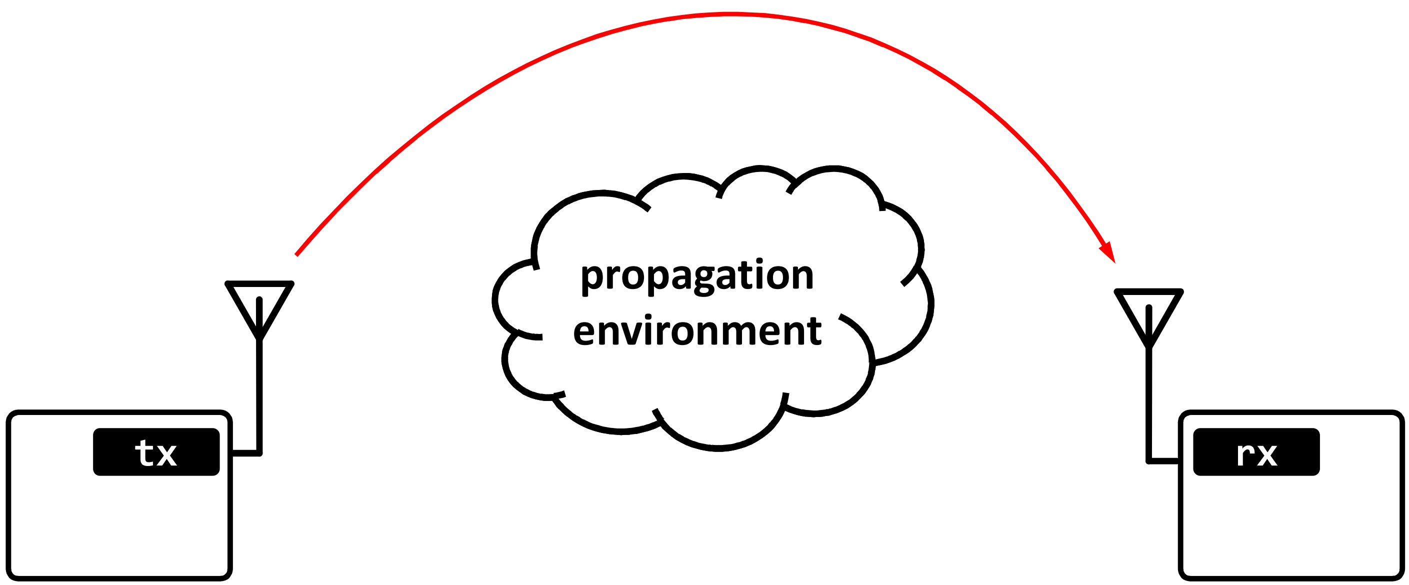
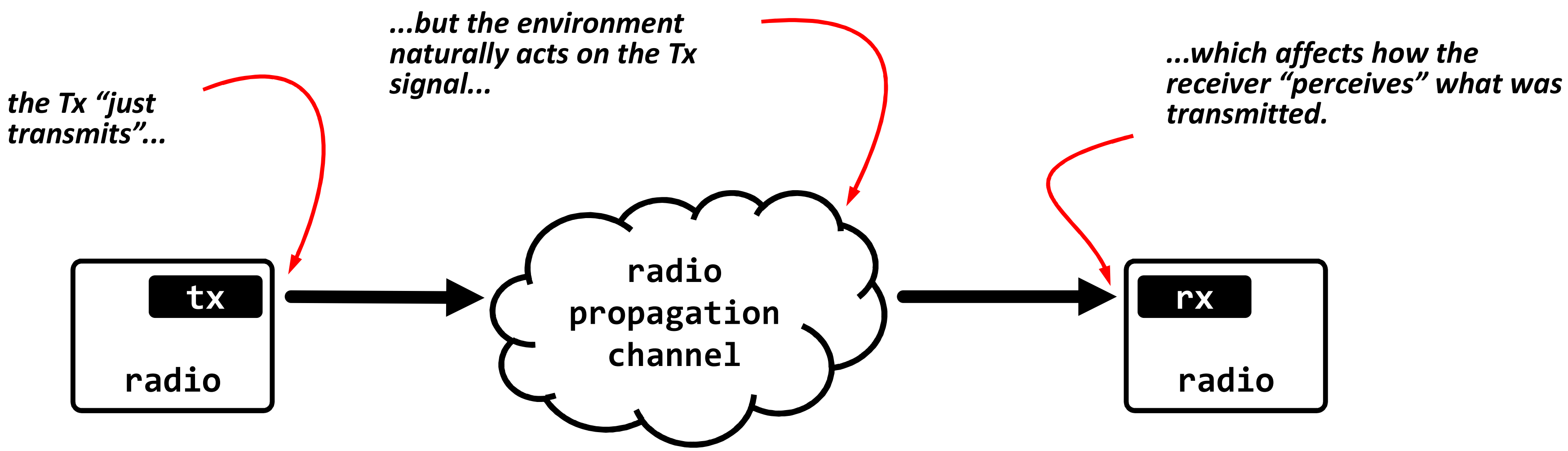
“Wireless” in practice:



Propagation from TX to RX:

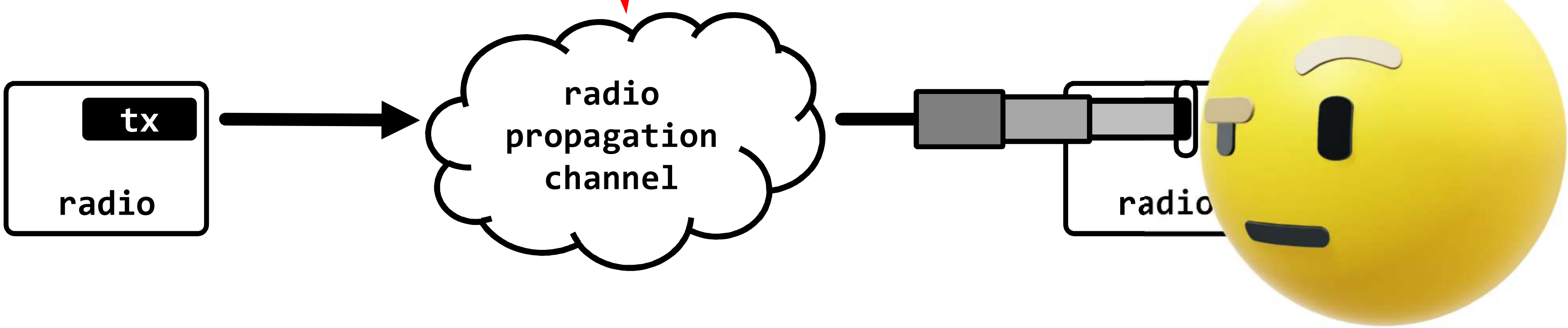


<u>key</u>: the test stimulus is then simply a set of TX signals that are modified to appear as Rx would perceive them in a real environment.

Desired test conditions:

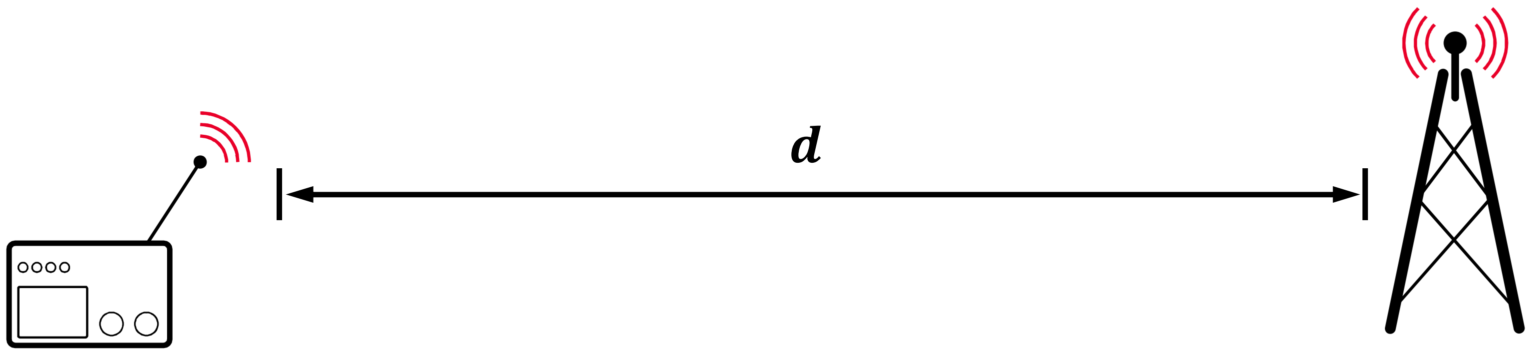
want RX to "see" the TX through the "lens" of the propagation environment.

the environment <u>modifies</u> the Tx signal.



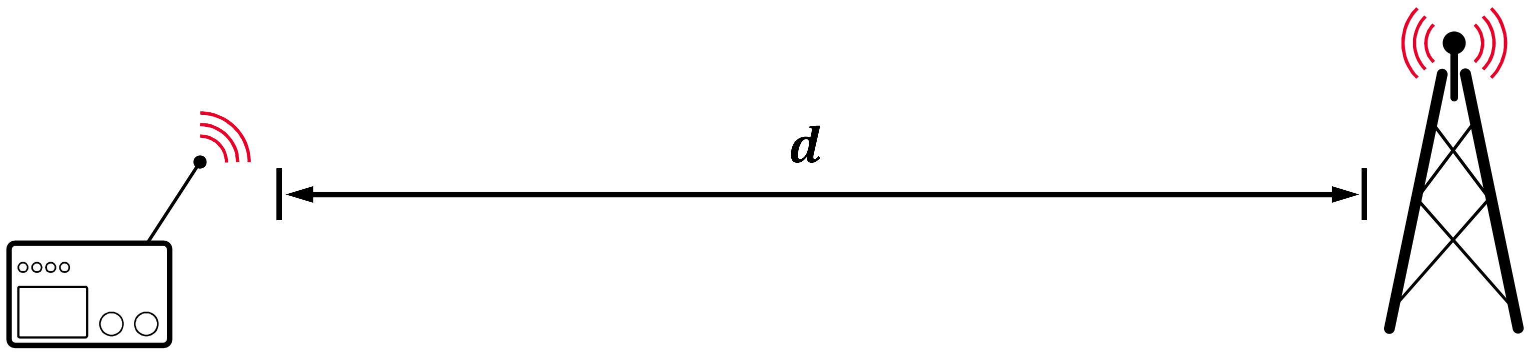
i.e. desired test strategy is based on the RX signal exhibiting the "effects" of the environment.

What are some of these “effects”?



- consider two radios communicating with each other, spaced some distance apart.
- separation → **propagation delay** (or “transit time”)
- $t = d/c$

What are some of these "effects"?

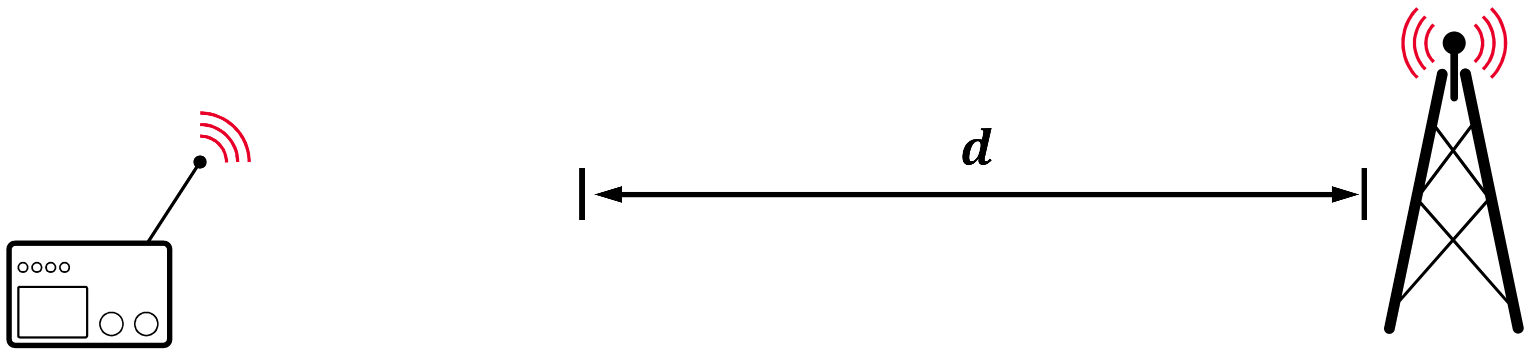


- separation + carrier frequency → **propagation loss**
- "free-space path loss model"

$$FSPL_{\mathrm{dB}} = 20\log_{10}(d) + 20\log_{10}(f) + 20\log_{10}(4\pi/c)$$

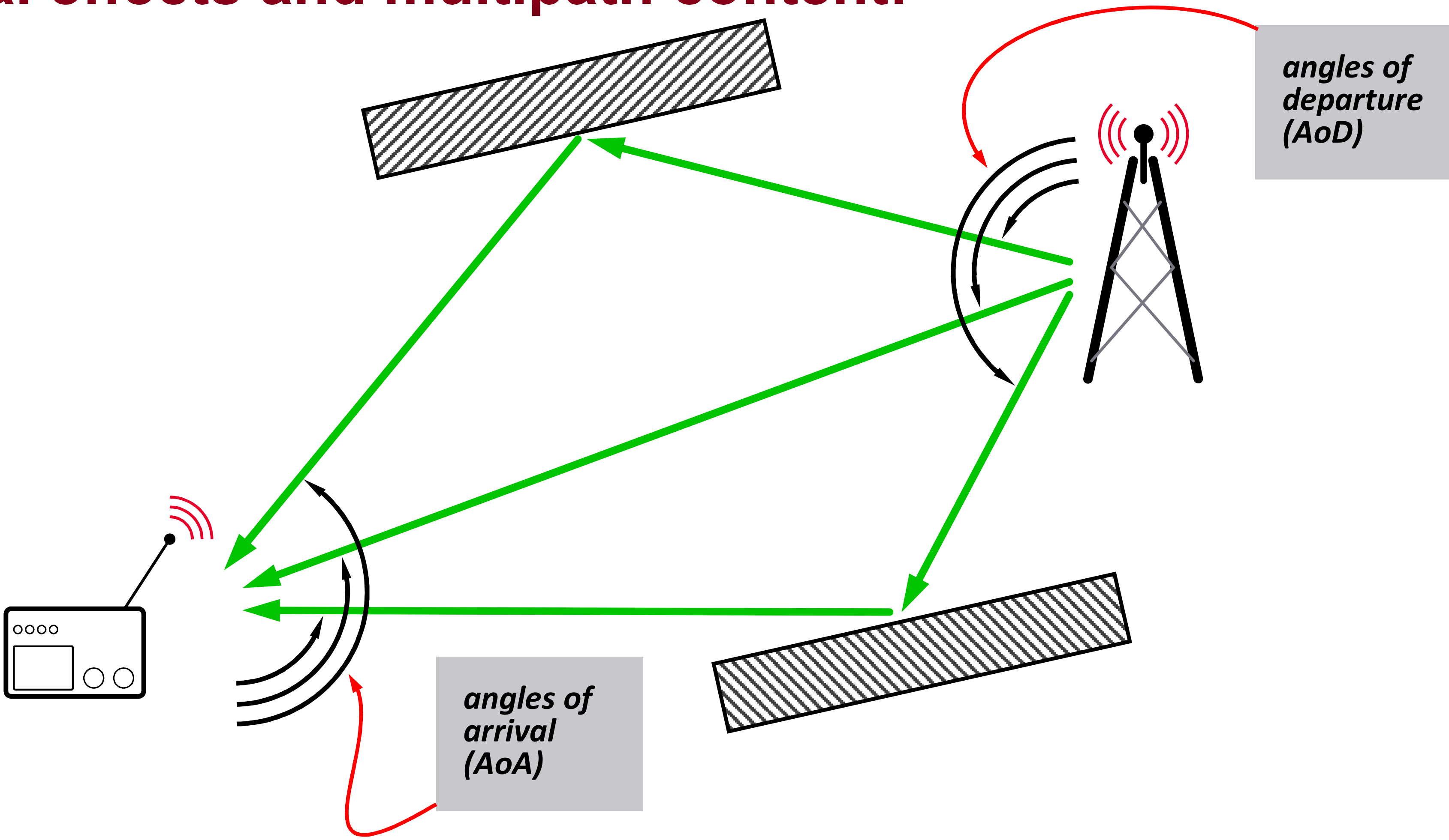
- other models…

What are some of these “effects”?



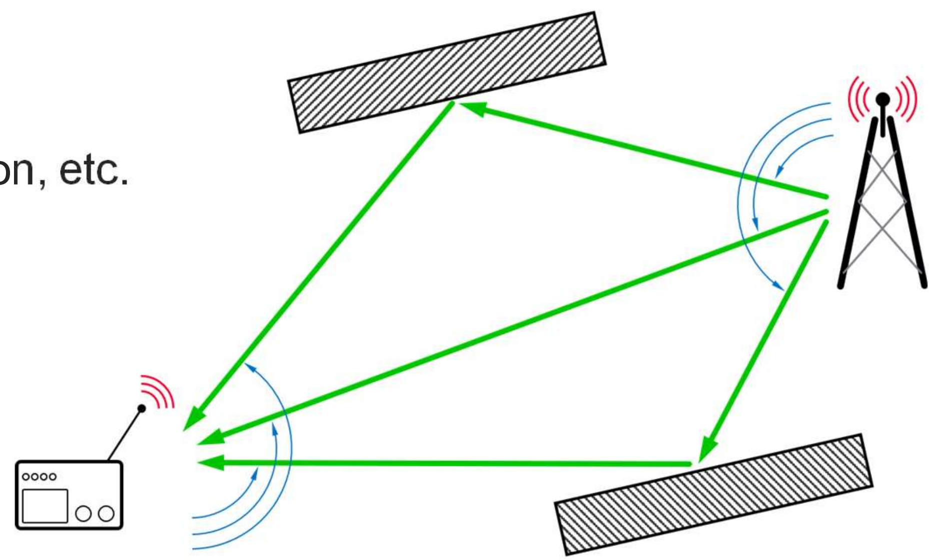
- movement → Doppler shift
- movement → separation is changing
- propagation delay and loss must also be changing in tandem if there is a Doppler shift!
- these effects are inextricably linked in real environment but lab test methods allow these to be examined individually.

Spatial effects and multipath content:



Channel behavior is not just a time-domain consideration.

- reflections of Tx signals create a multi-path profile.
- copies of the Tx signal arrive at Rx at different delay increments.
  - time domain effect
- reflections must depart/arrive at different angles
  - spatial domain effect
- other effects: MIMO correlation, cross-polarization, etc.



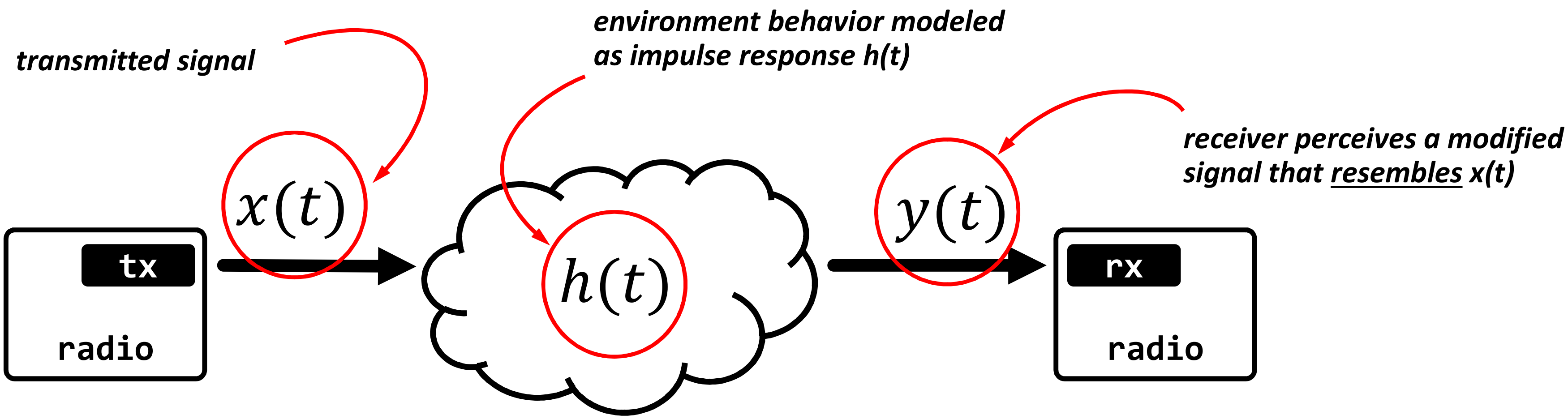
For further information…

- **“Radio Propagation Channel Modeling Fundamentals”**
  (a webinar by Mike Alaimo)
- **www.keysight.com/find/5Gwebinars**

Bring in some math to form a modeling and test strategy:

- We can represent these effects as an impulse response (or transfer function).
- I'm taking some liberties with the math notation.
- Let's build a test strategy based on this understanding of what happens in the real operating environment.

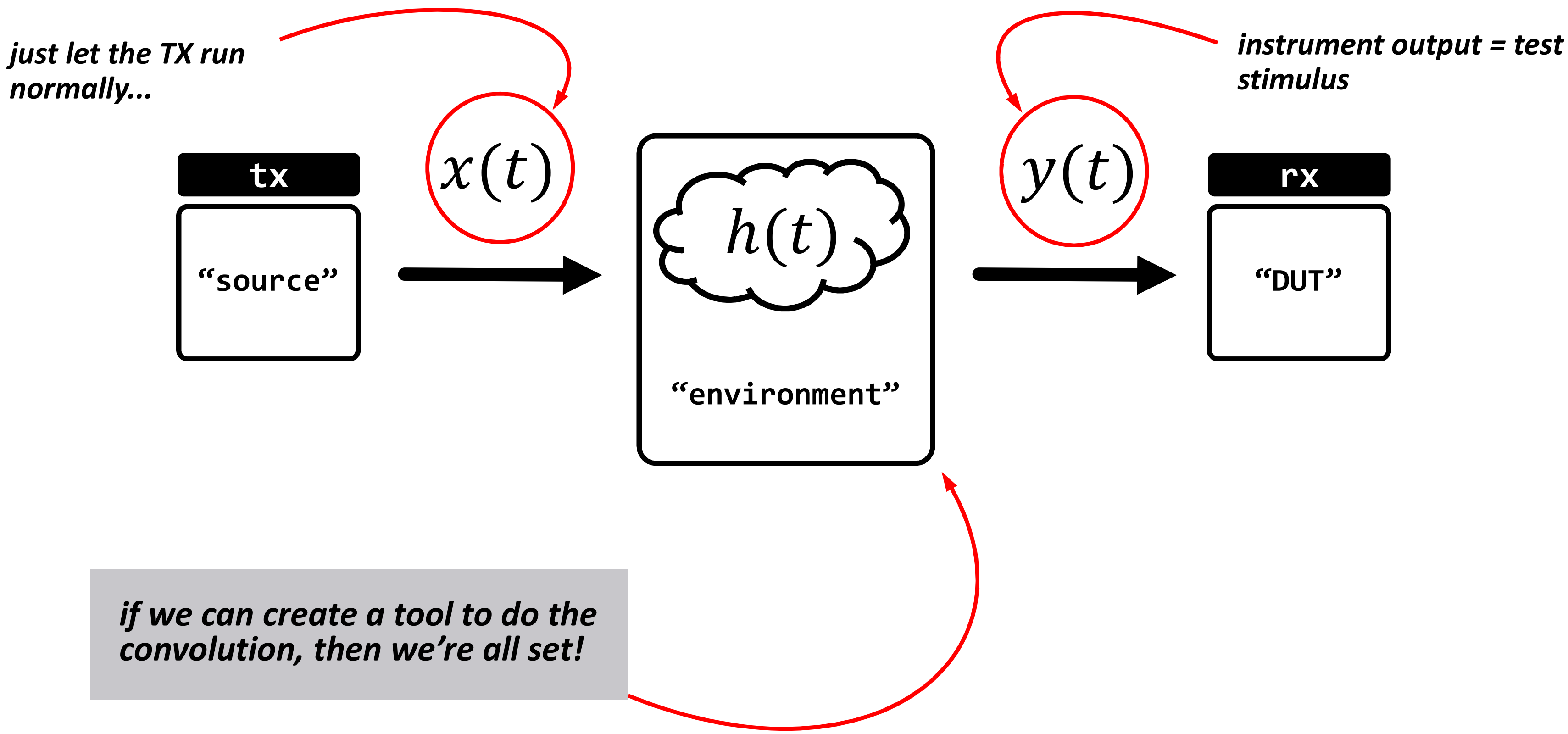
There is an engineering method to handle these effects…



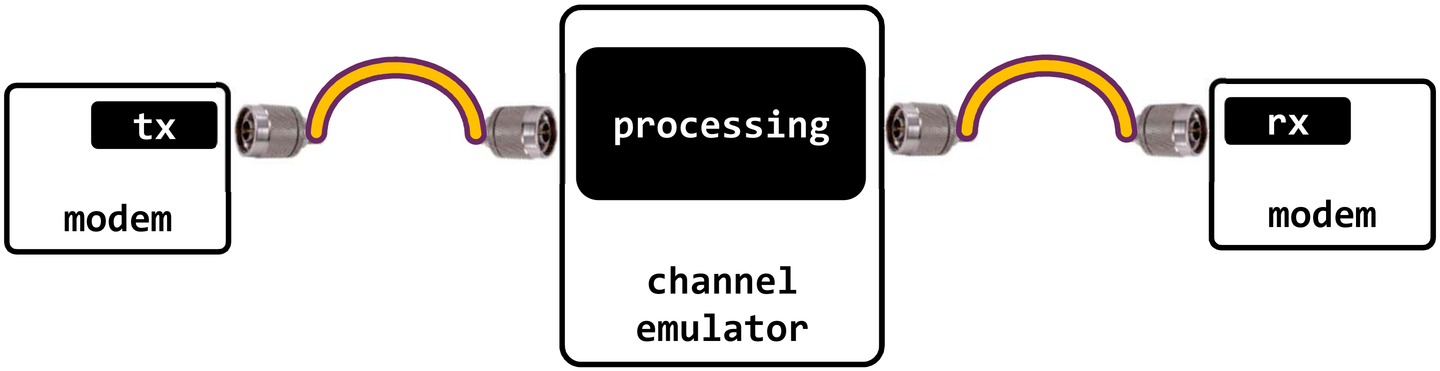
$$y(t) = x(t) * h(t)$$

convolution operation

Desired method for end-to-end system testing:

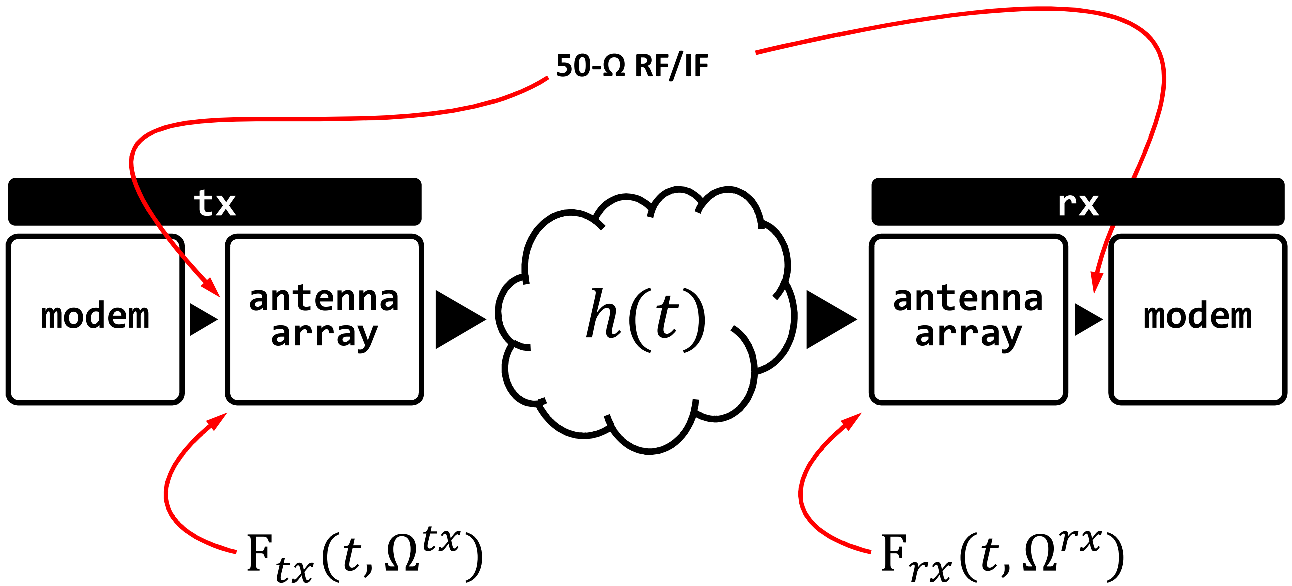


Basic implementation for end-to-end system testing:



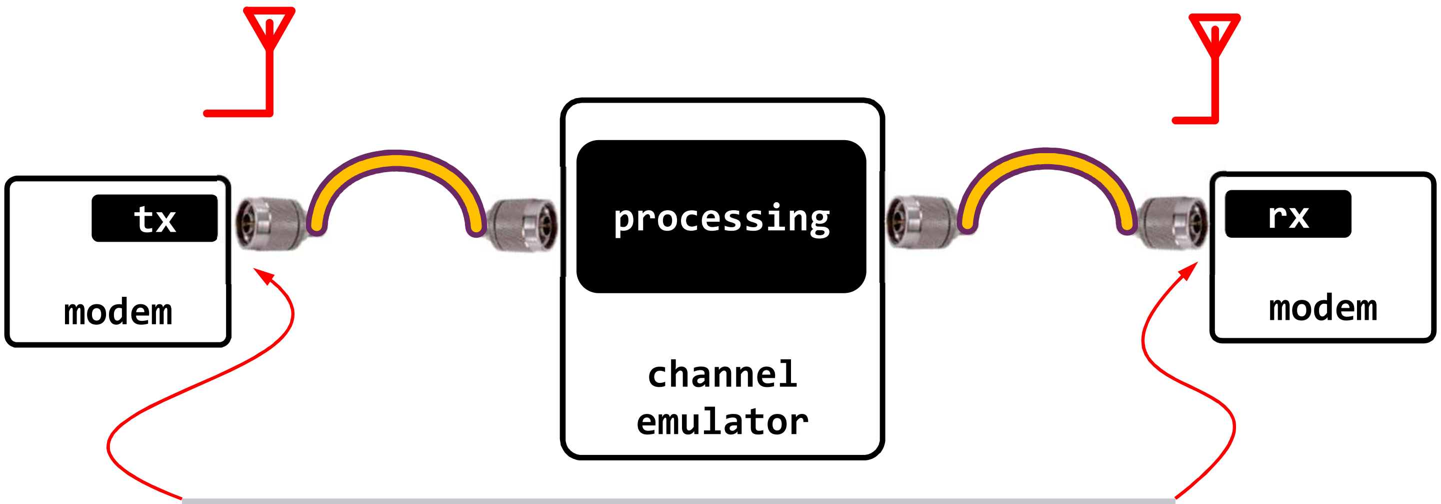
- *this works well because it requires no modification of the radios—just connect and let them operate normally.*
- *is there any downside?*

Radio/DUT end-to-end detail:



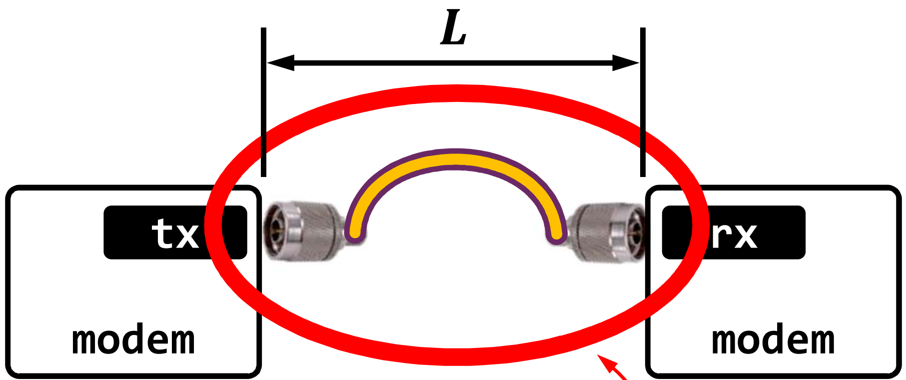
- ***Antenna radiation patterns are functions of 3D-space (AoA, AoD, AS).***
- ***...and function of time if terminals move and/or change orientation.***

How well does this hold up?



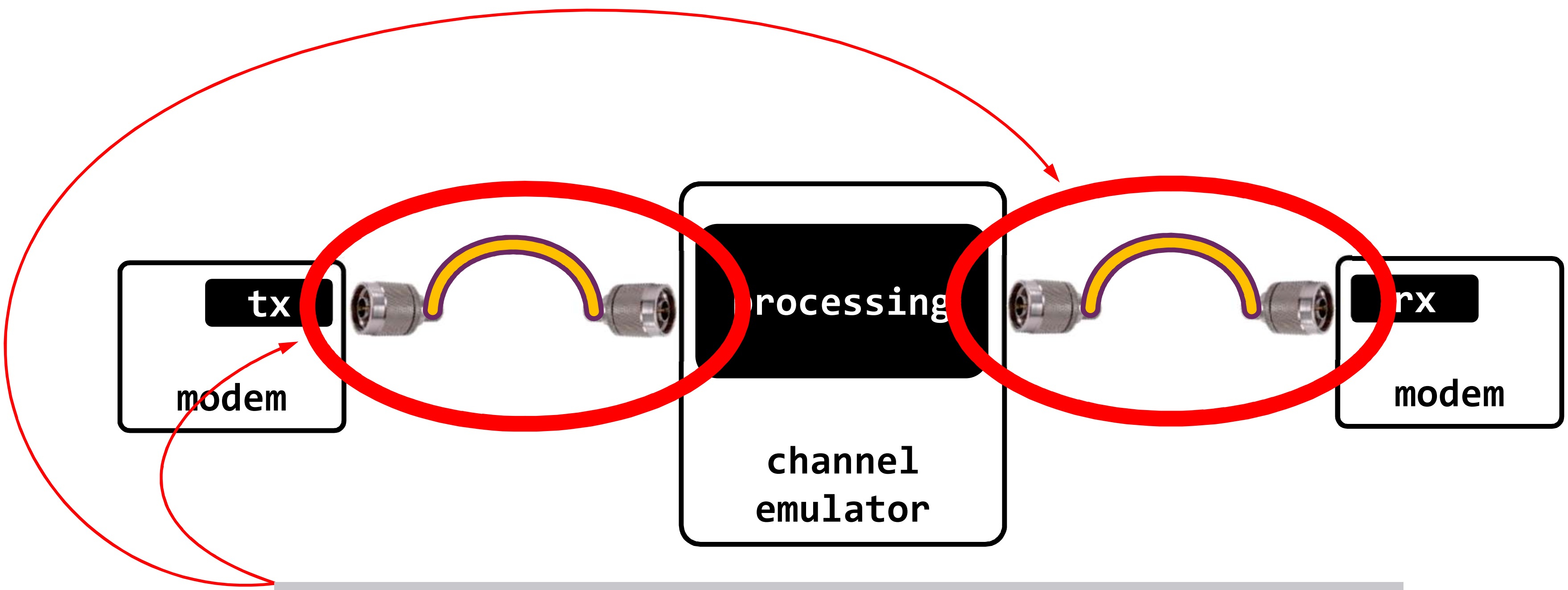
- *antennas should be connected here!*
- *antennas are key part of wireless system operation...*
- *but we had to remove them to connect the instrument!*

What is the transfer function for this coupling?



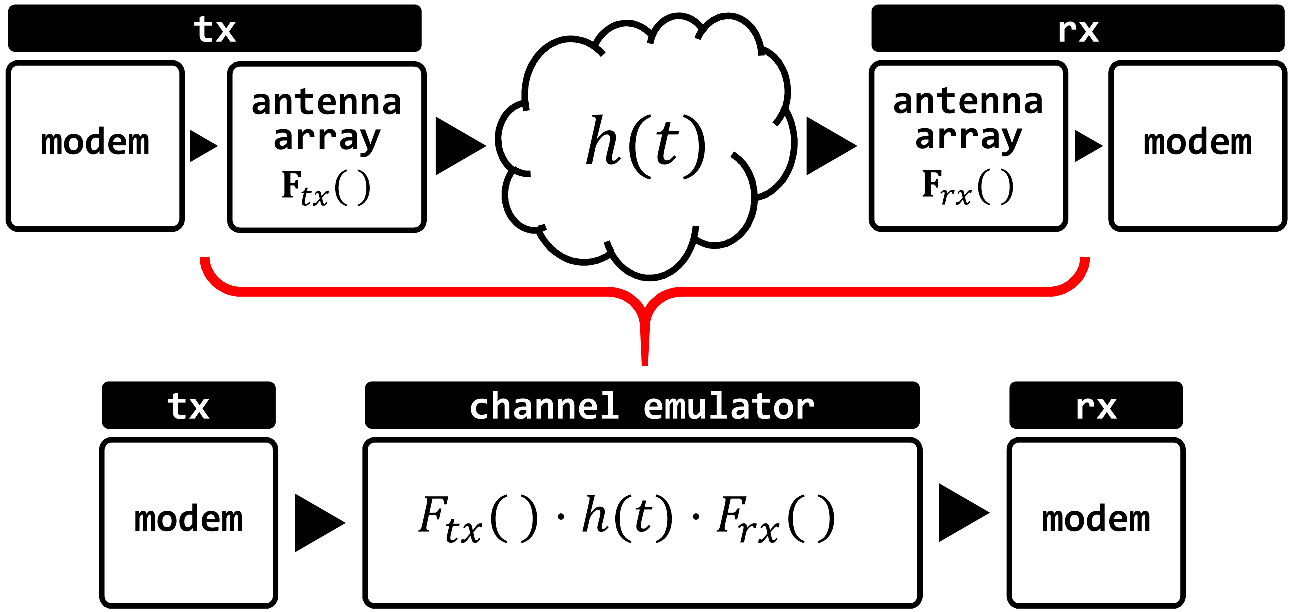
$$\alpha \boldsymbol{e}^{-\boldsymbol{j}\left(\frac{\boldsymbol{\omega L}}{\boldsymbol{c}} + \varphi\right)} \; ; \alpha < 1$$

Does that affect our end-to-end strategy?



- *not really, if it's just a small attenuation and a small/known delay or phase shift.*
- *can consider these negligible or calibrate out of setup if needed...*

What is the desired end-to-end transfer function?

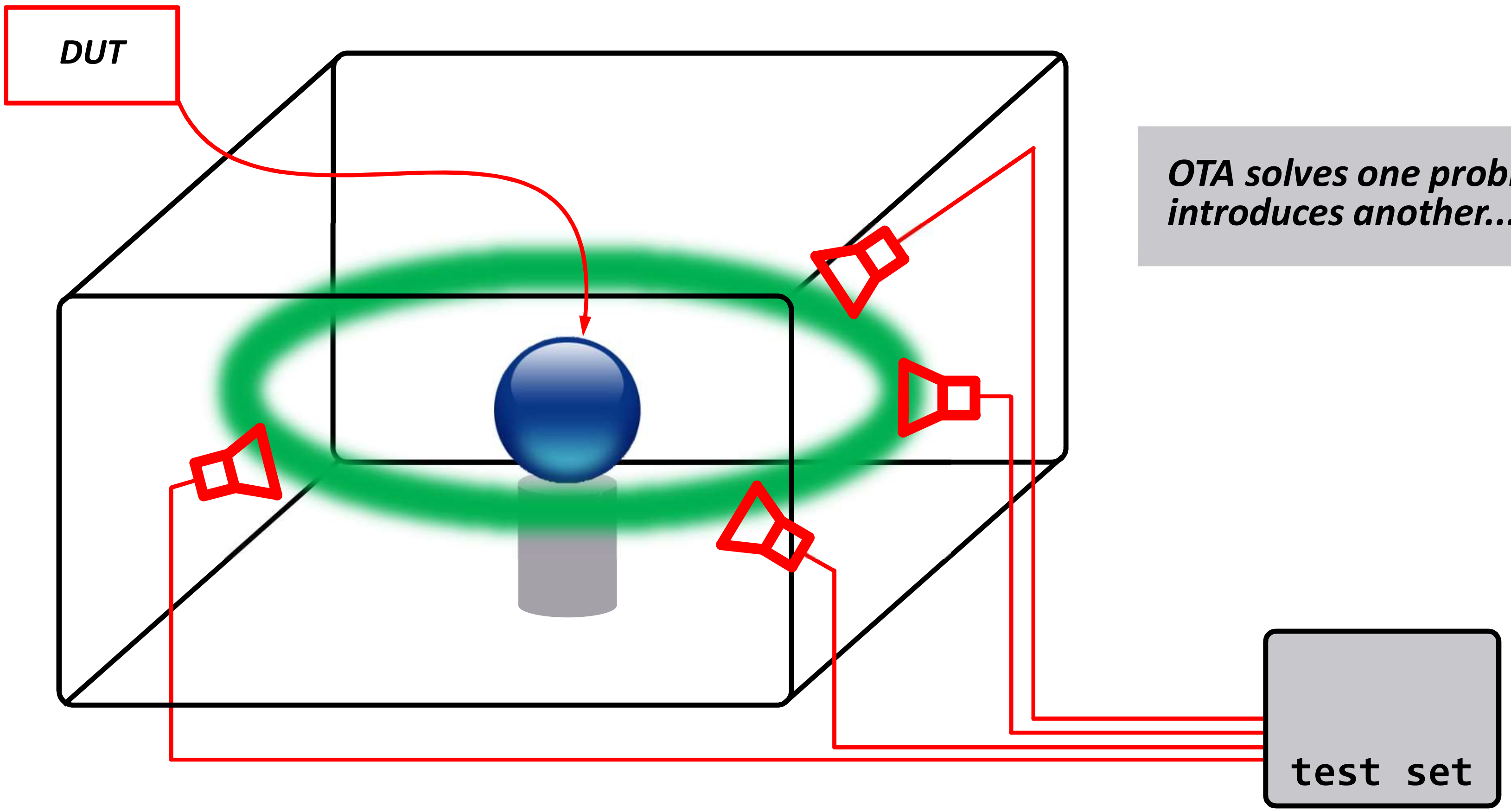


- *this can be done in the lab with current state of the art!*
- *...but not all emulators can do this...<u>requires a particular instrument architecture</u>.*

Does this method support 5G/mmW testing?

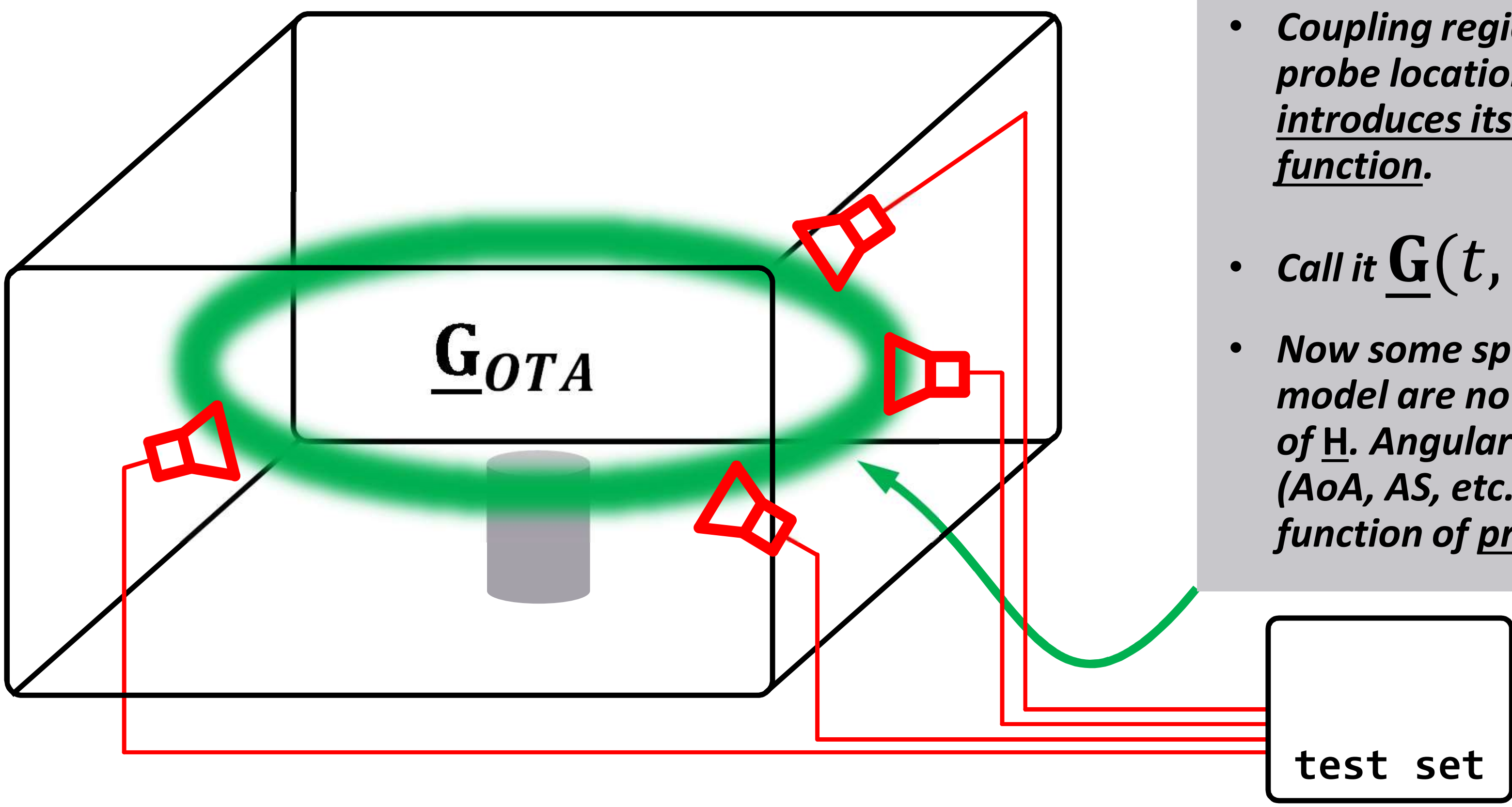
- Specifically, can we use this cabled/conducted approach for 5G and mmW testing?
- Why not:
  - Form factors don't allow it.
    - No coax connectors on devices.
    - Might be able to use an "antenna jig" for conducted connections, depending on manufacturer.
  - Cables don't work as well at mmW frequencies.
    - Waveguides might not be feasible alternative.
  - Need to get creative…use the flexibility you have in different scenarios.
  - Consider replacing the cable with an RF enclosure ("chamber")
- Two options:
  - Find a way to use the HW antennas as they are;
  - Incorporate them into the emulated SW model.

If we can't use cables, then consider a radiated approach:



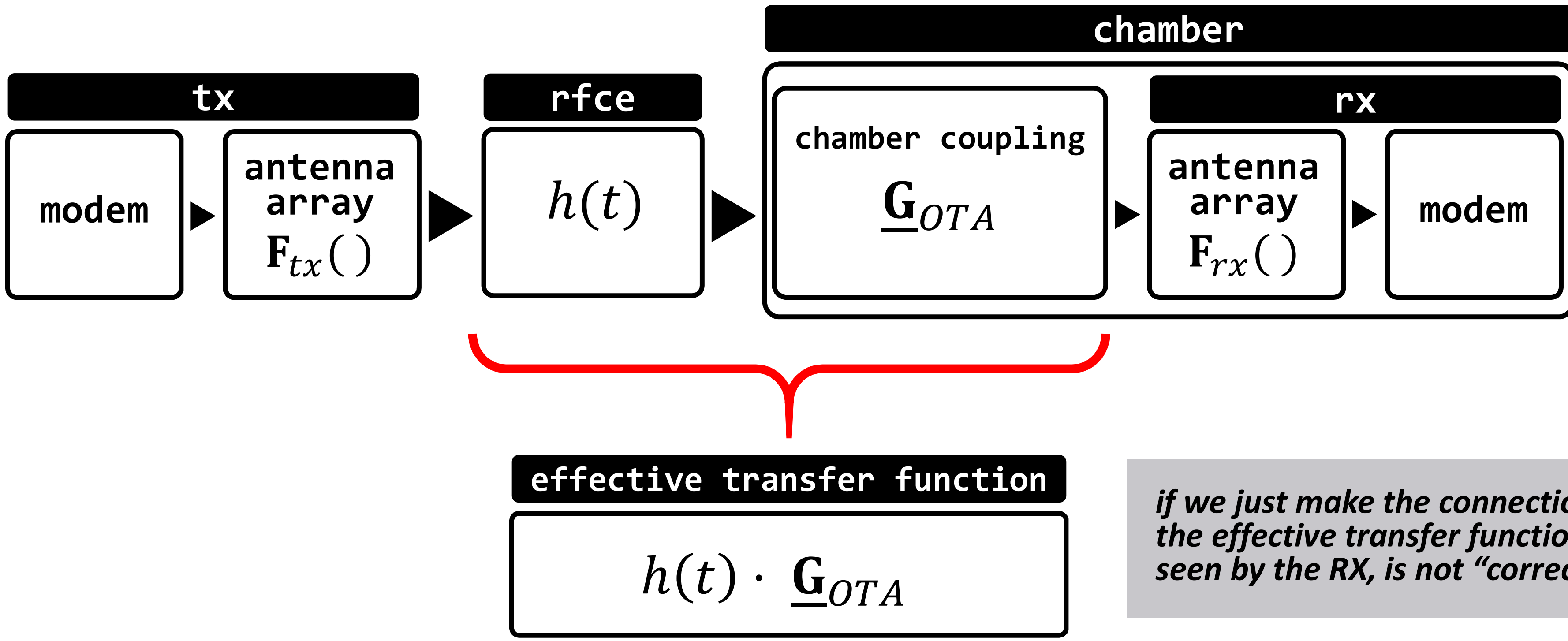
OTA solves one problem, but introduces another...

"Cable replacement": what is the TF of this coupling?



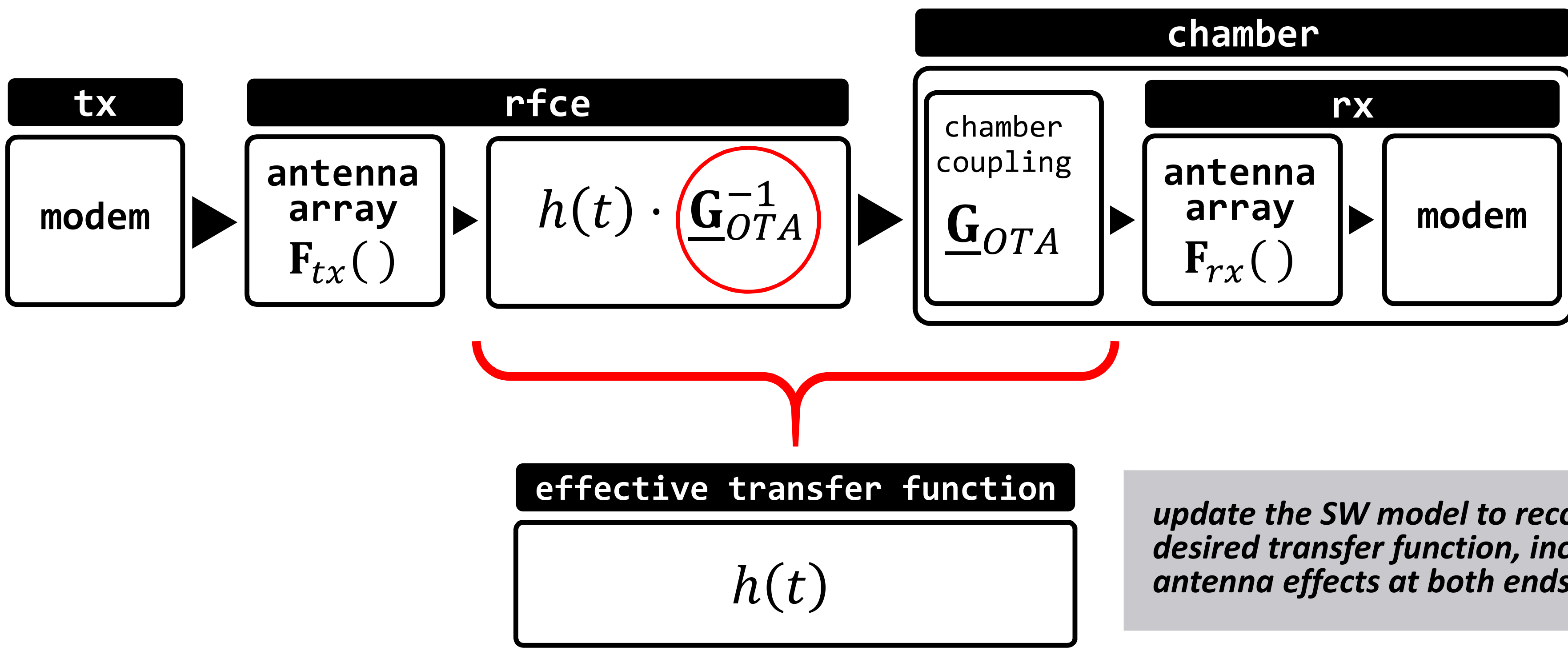
- ***Coupling region between probe locations and DUT <u>introduces its own transfer function</u>.***
- ***Call it*** $\underline{\mathbf{G}}(t, \boldsymbol{\Omega}, P_k^{v,h})$
- ***Now some spatial aspects of model are not just a function of <u>H</u>. Angular parameters (AoA, AS, etc.) are now a function of <u>probe index</u>.***

Transfer function analysis: uncompensated setup



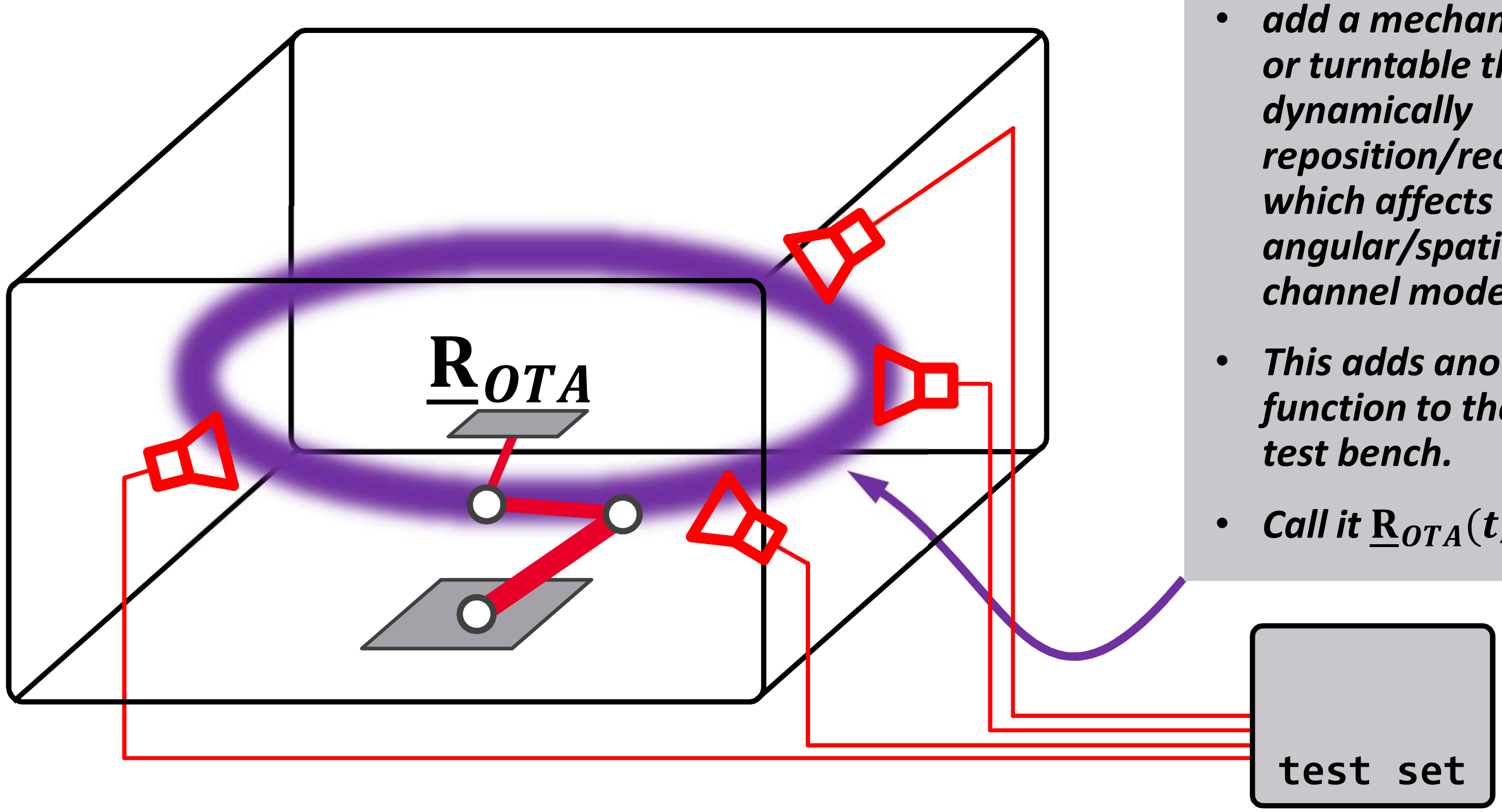
if we just make the connections, the effective transfer function, as seen by the RX, is not "correct".

Transfer function analysis: compensated setup 1



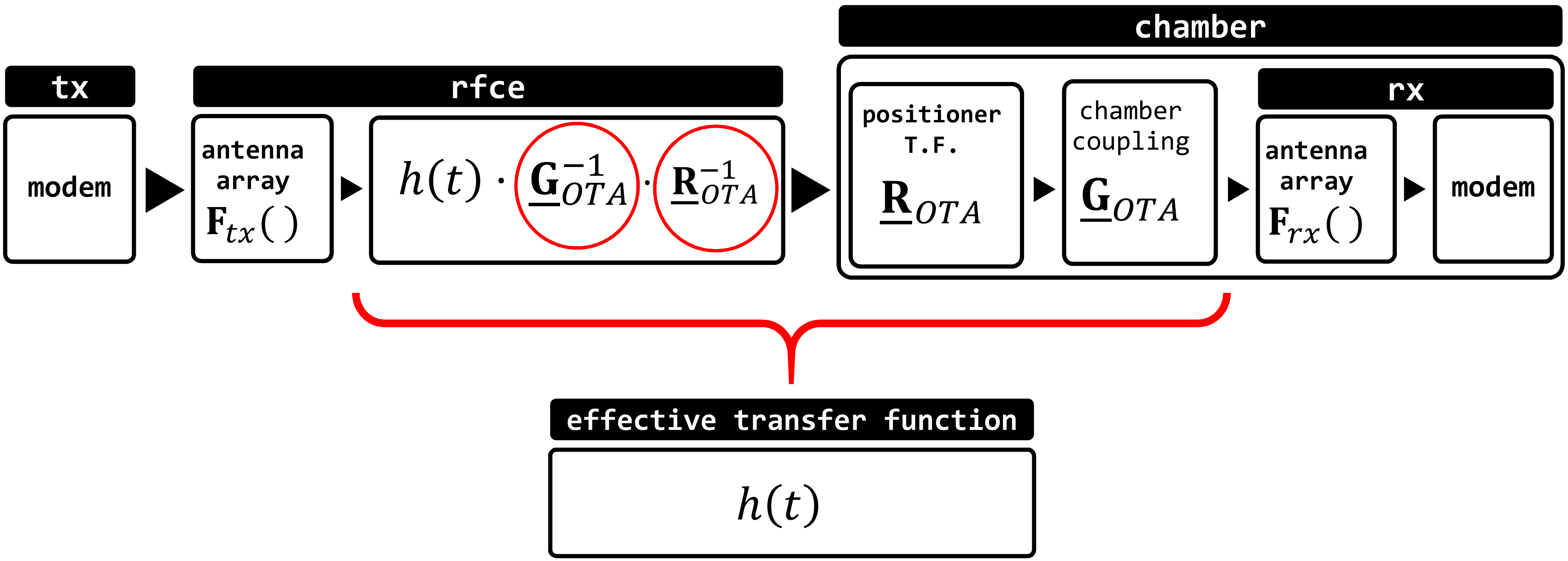
update the SW model to recover the desired transfer function, including antenna effects at both ends!

Chamber upgrades: turntables and positioners

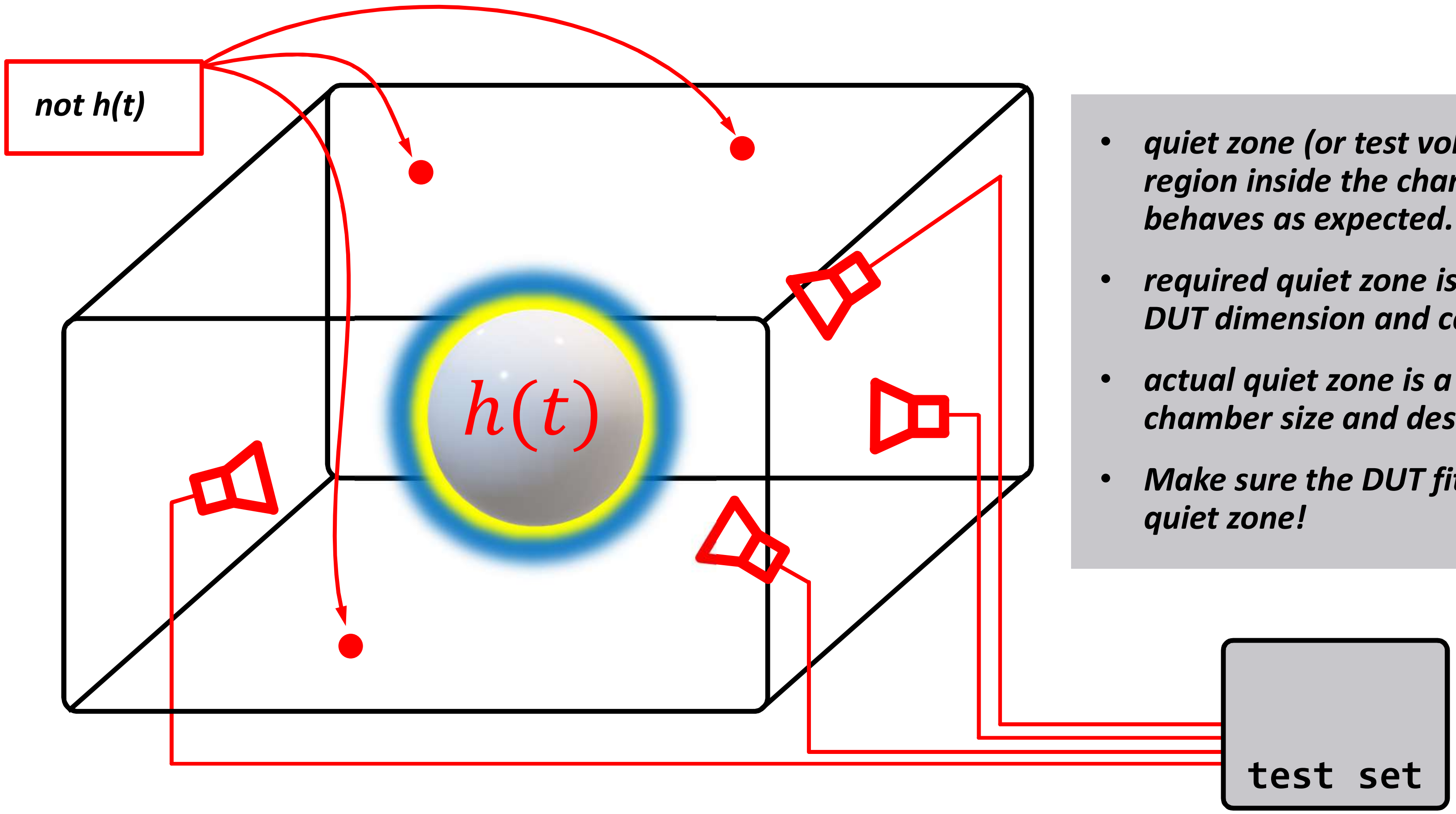


- *add a mechanical positioner or turntable that can dynamically reposition/reorient the DUT, which affects the angular/spatial part of the channel model..*
- *This adds another transfer function to the end-to-end test bench.*
- *Call it* $\underline{\mathbf{R}}_{OTA}(t, \Omega)$.

Transfer function analysis: compensated setup 2

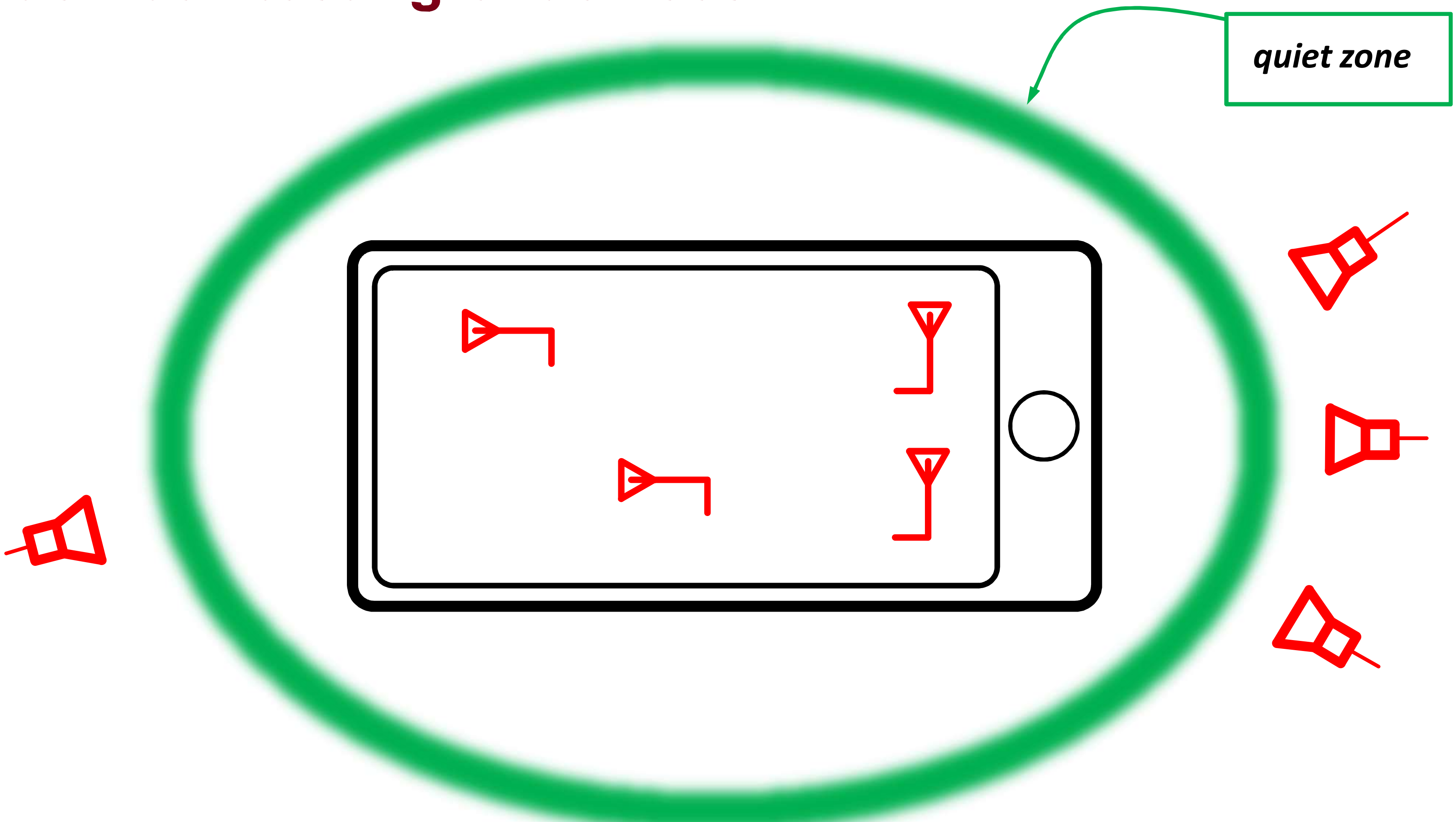


Anechoic chamber quiet zone/test volume

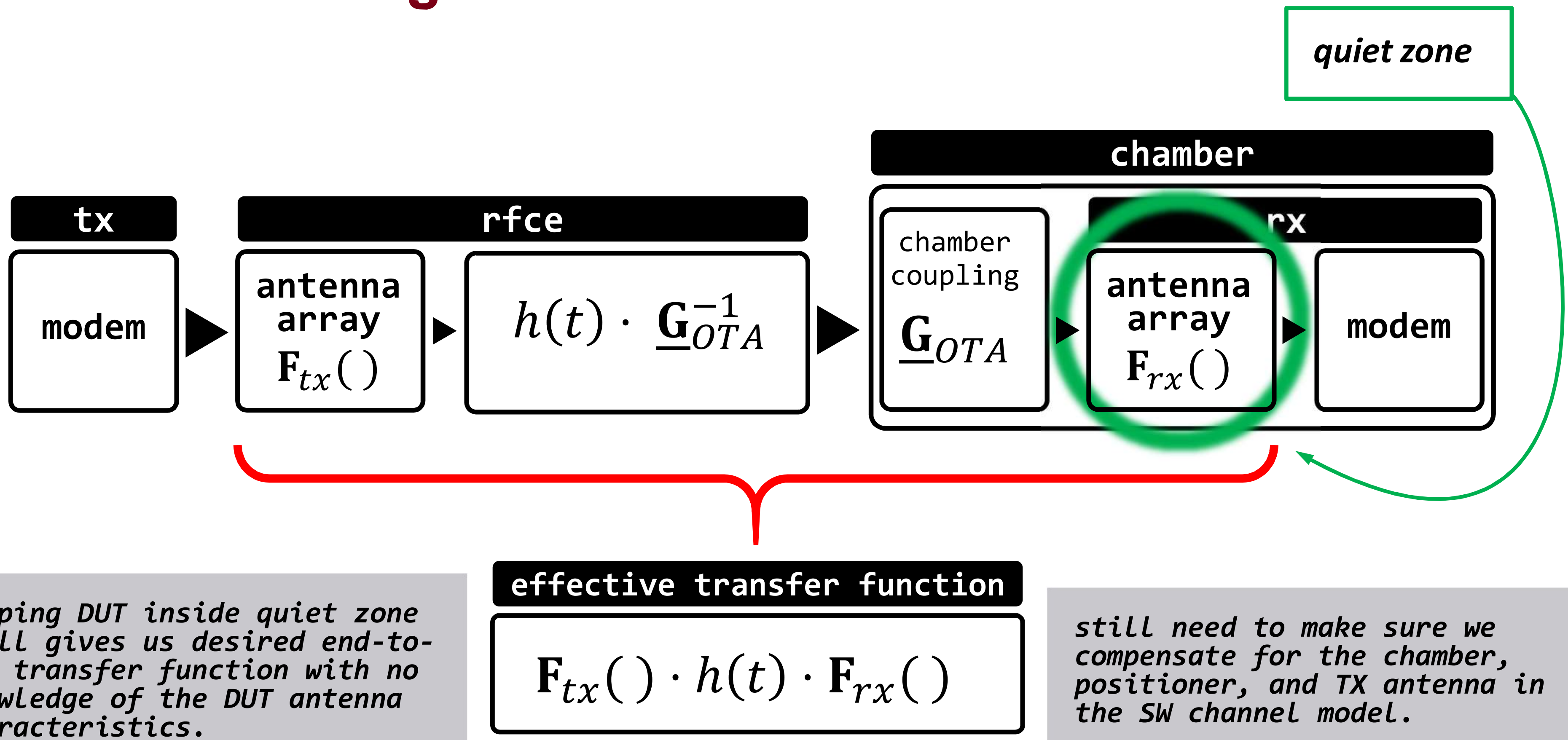


- *quiet zone (or test volume) is the 3D region inside the chamber where* h(t) *behaves as expected.*
- *required quiet zone is a function of DUT dimension and carrier frequency.*
- *actual quiet zone is a function of chamber size and design.*
- *Make sure the DUT fits inside the quiet zone!*

Black-box testing of devices:



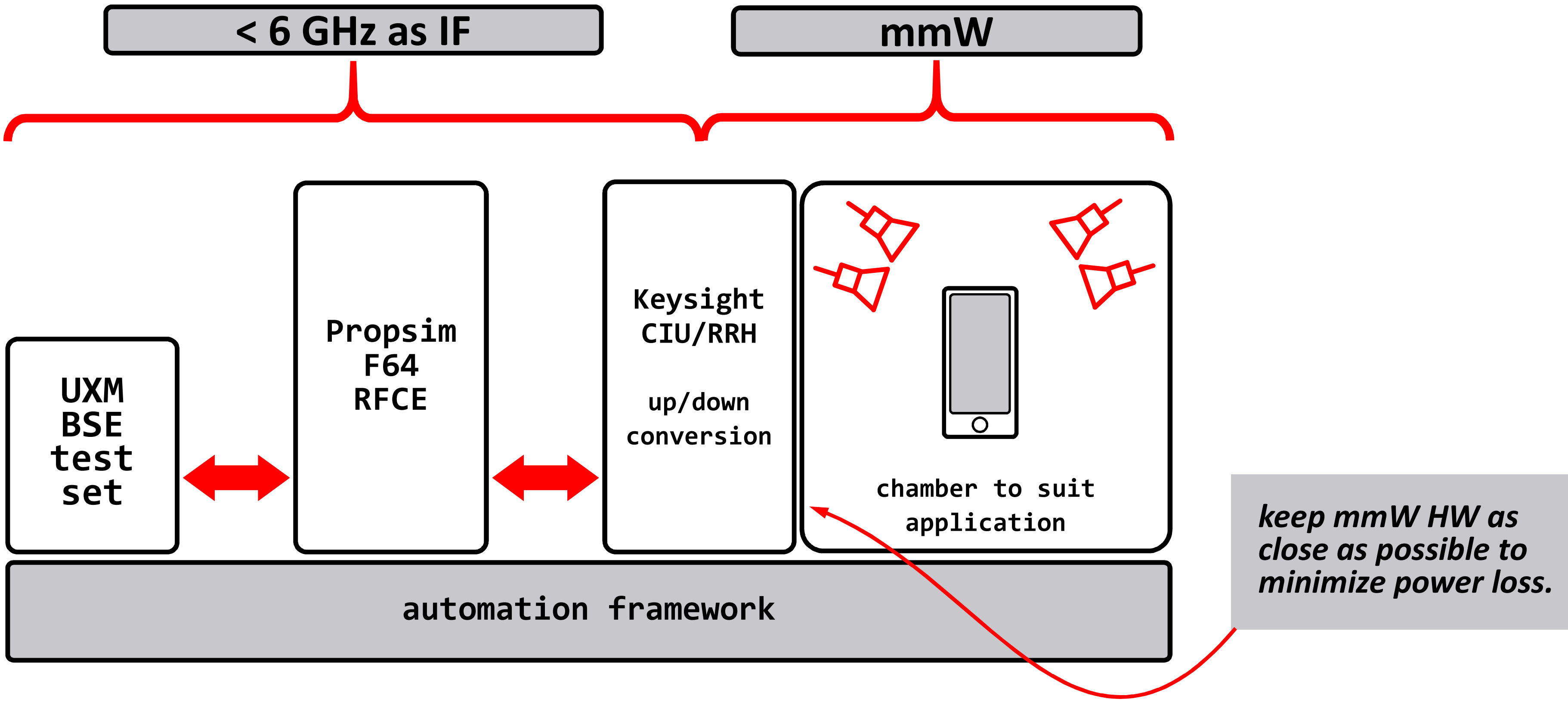
Black-box testing of devices:



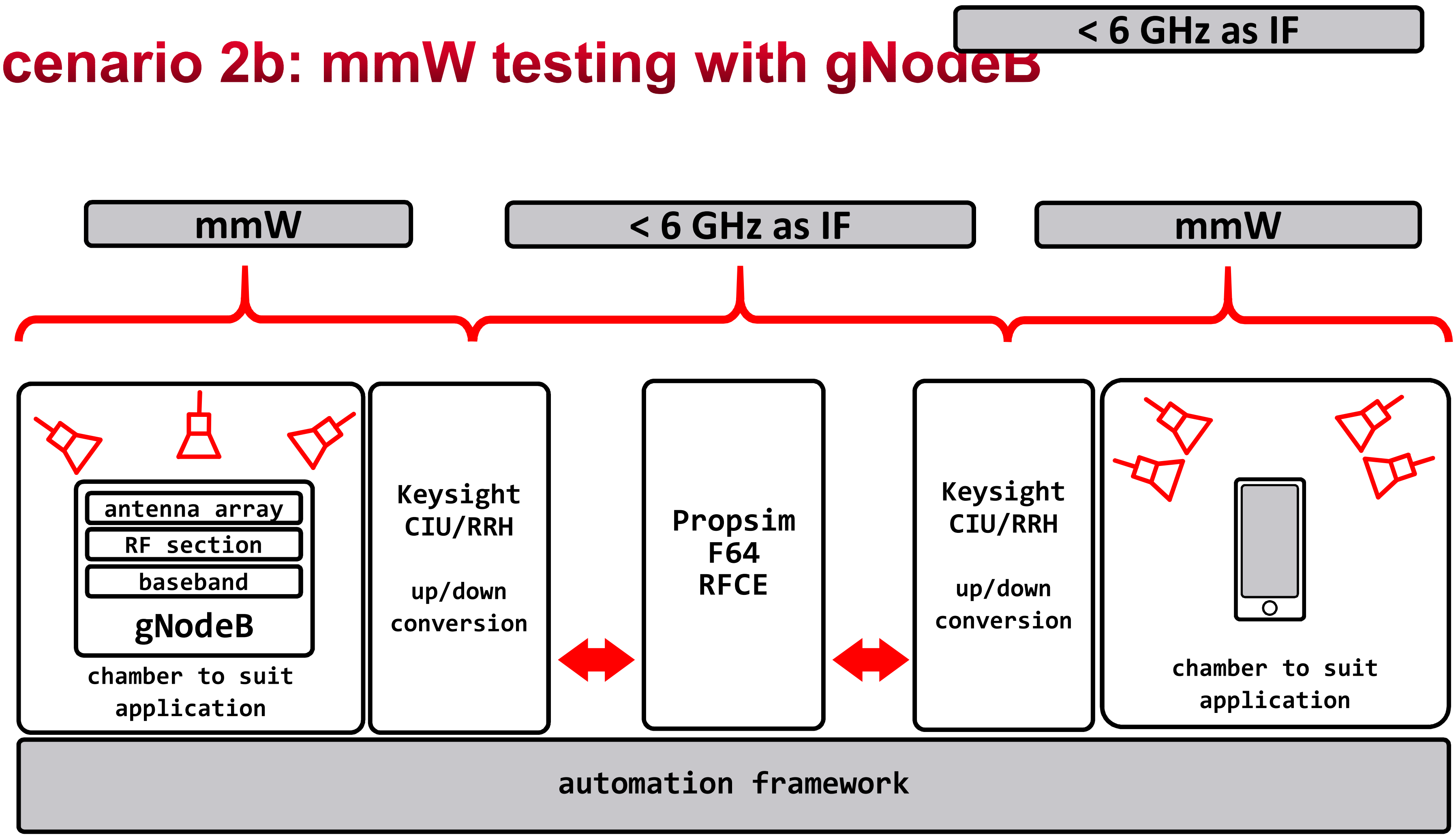
keeping DUT inside quiet zone still gives us desired end-to-end transfer function with no knowledge of the DUT antenna characteristics.

still need to make sure we compensate for the chamber, positioner, and TX antenna in the SW channel model.

Scenario 1: test mmW device with frequency-shifted setup



Scenario 2b: mmW testing with gNodeB



Chamber / OTA Use Types

5G DEVICE END-END SOLUTIONS

RF/Antenna	Protocol/Functional Single Link	Beamforming with Clean channel	Mobility and Performance
• Clean channel • Far Field • RF Test • Link performance • Ch 6 & 7 RCT	• Cable replacement • Near field • Single antenna • PCT	• Cable replacement • Near field • 3 antennas • Mobility • Beamforming • PCT	• Far field • 4 active antennas • Mobility • Full Beamforming • RRM RCT
 *CATR*	 *RMTC*	 *2D MPAC*	 *3D MPAC*

Questions?

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