Silicon Flatirons

Harm Claim Thresholds

Incorporating receiver performance in spectrum management without using receiver standards

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Questions?

Summary

Receiver are (at least) half the problem with interference

‘Receiver standards’ are better than doing nothing

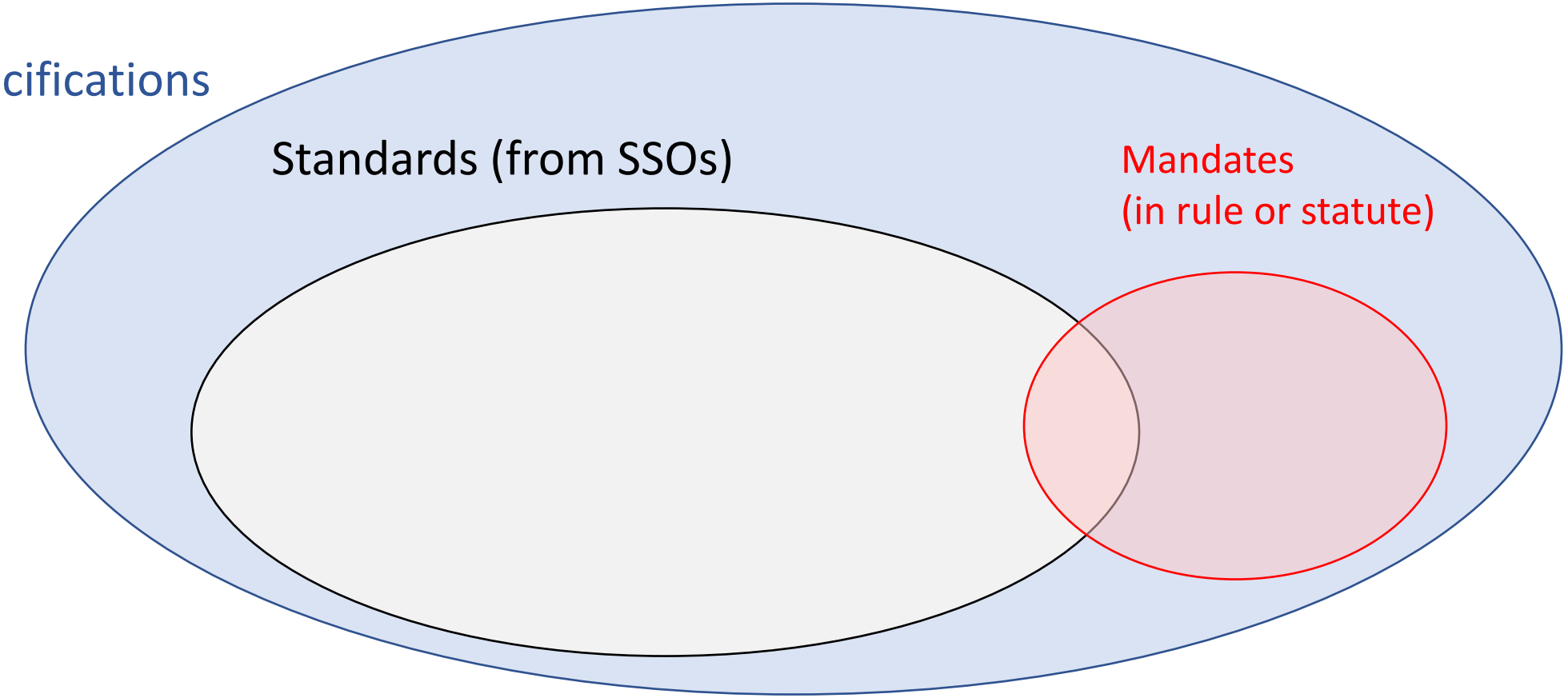
But – they’re hard to establish

An alternative: Harm claim thresholds (aka interference limits)

How the TAC can help move the conversation forward

Terminology

Rx specifications, standards, and mandates



FCC TAC (2014) nomenclature

Interference limits policies

- ‘Ways to describe the environment in which a receiver must operate without necessarily specifying receiver performance’

Harm claim thresholds

- ‘In-band & out-of-band interfering signals that must be exceeded before a system can claim that it is experiencing harmful interference’

Receiver standards & mandates

Receiver standards are hard, mandates harder still (1)

Receiver specs are a design output, not an input (flow chart ☛)

- Receiver performance is just one factor in a *system*'s response to the RF environment

Rx regulatory certification more complicated than Tx (Cardboard Box Test ☛)

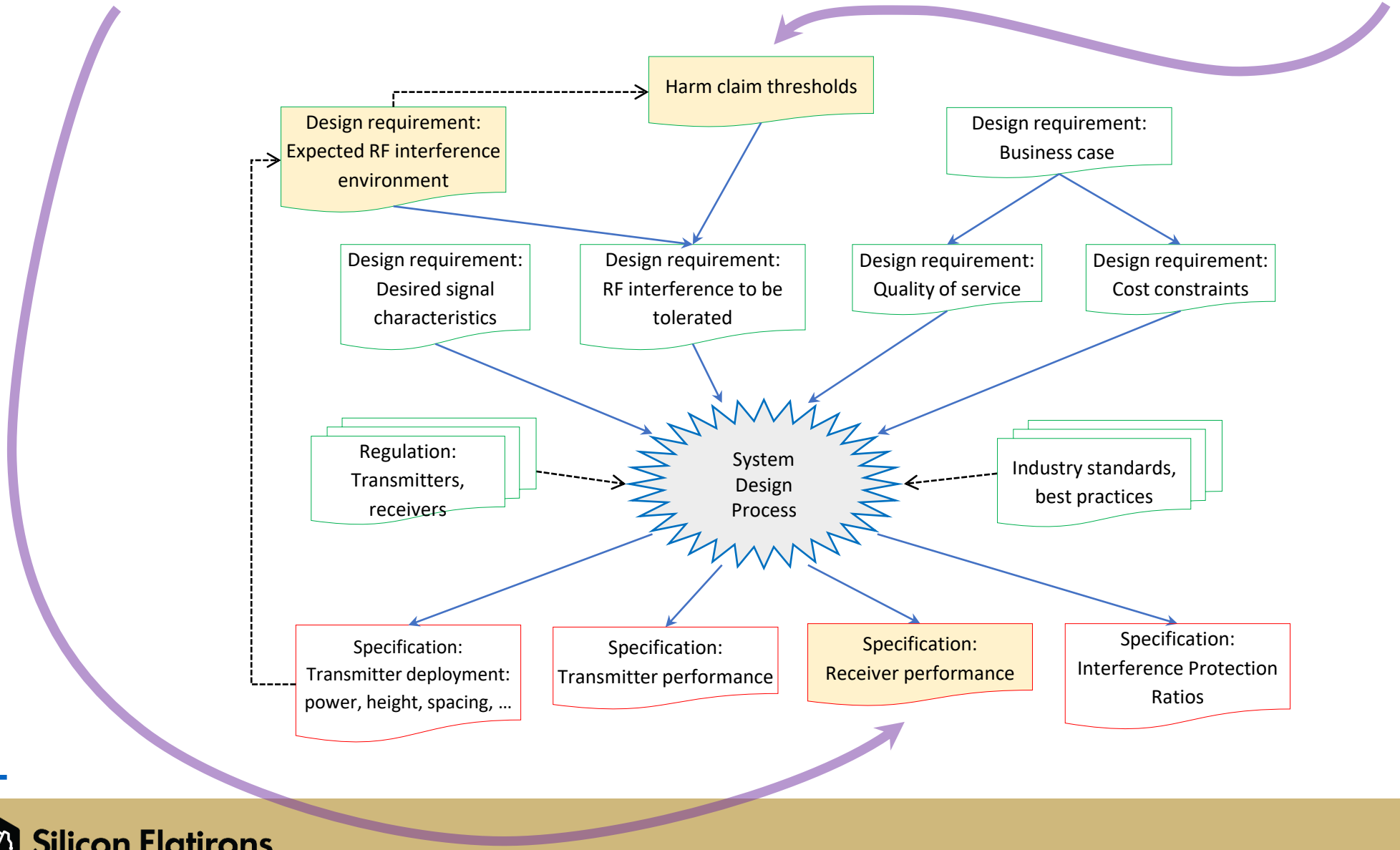
Requires detailed, downstream trade-offs between Rx and Tx interests

Encode today's understanding of best use (actually, yesterday's)

Not technology or service neutral

FCC authority?

Rx specs are way downstream from the IX env'm't



Inputs in GREEN
Outputs in RED

Certifying Rx ≠ Tx: The Cardboard Box Test

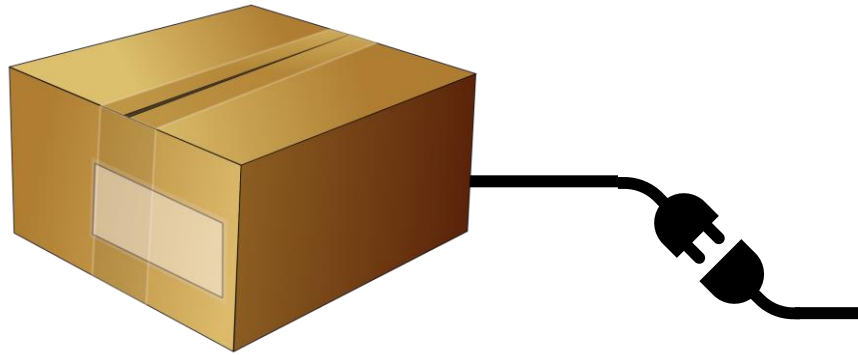
Receiver testing requires verifying the proper operation of the receiver in the presence of specified interference

Proper operation is in the eye of the beholder

- E.g., what is a suitable bit error rate (BER)?

Testing requires access to –

- the receiver's output (e.g., to measure BER)
- and often intermediate taps between RF input and signal output (e.g., to measure I/N degradation)



A receiver standard: 3GPP, UE radio transmission and reception, FDD (Table of Contents)

3GPP TS 25.101
v16.1.0 (2019-03)
pp. 94–162 (68 pages!)

Major headings include:

- Reference sensitivity level
- Maximum input level
- Adjacent Channel Selectivity
- Blocking characteristics
- Spurious response
- Intermodulation characteristics
- Spurious emissions

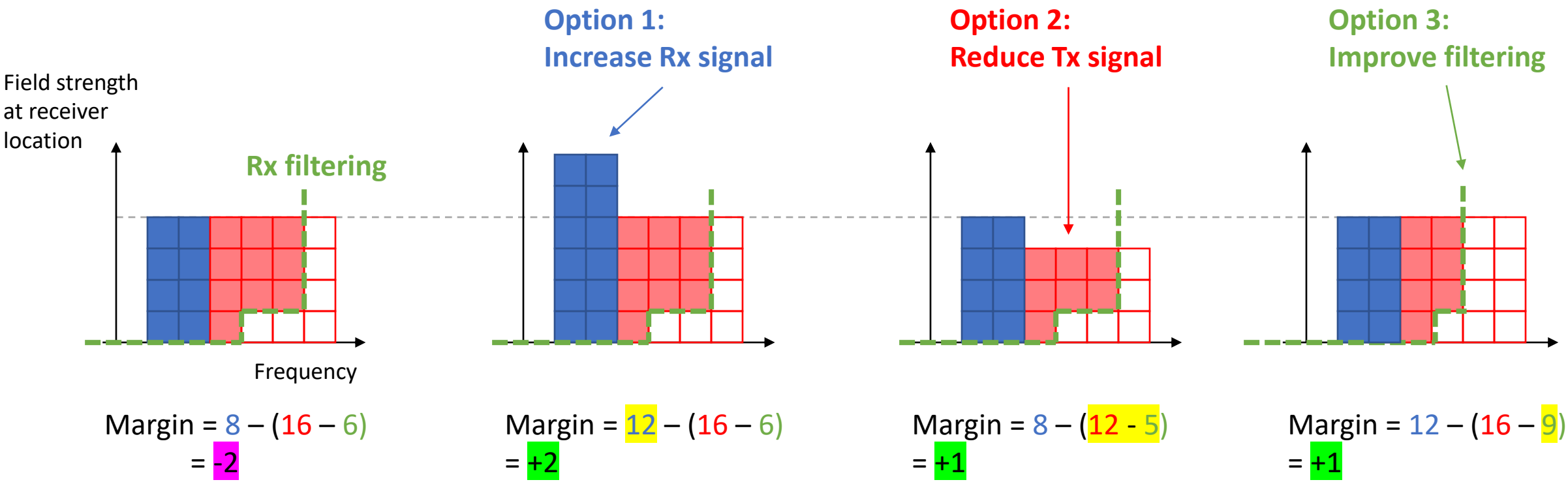
Some Tx/Rx trade-offs (non-cochannel, simplified)

Margin = desired signal – undesired signal + receiver filtering

Given poor margin, receiving system can

(0) tolerate it and fix it higher up the stack,

or improve it by (1) increasing its Rx signal, (2) forcing a reduction in Tx signal, or (3) improving its Rx filtering



Margin = 8 – (16 – 6)
= -2

Margin = 12 – (16 – 6)
= +2

Margin = 8 – (12 - 5)
= +1

Margin = 12 – (16 – 9)
= +1

Receiver standards are hard, mandates harder still (2)

Receiver specs are a design output, not an input (flow chart)

Rx regulatory certification more complicated than Tx (Cardboard Box Test)

Requires detailed, downstream trade-offs between Rx and Tx interests

- Intra-industry standards doable … inter-industry very hard
  - Tussles cross industry (service) boundaries – need regulatory arbitration
  - "Selection of receiver parameters [is the] most frequent single issue leading to delayed citation of [Harmonised Standards]" (ETSI webinar, 2021)

Encode today's understanding of best use (actually, yesterday's)

- not future-proof or future-oriented

Not technology or service neutral

FCC authority?

The evolving European view

"36. An updated vision regarding receivers and standards could include:

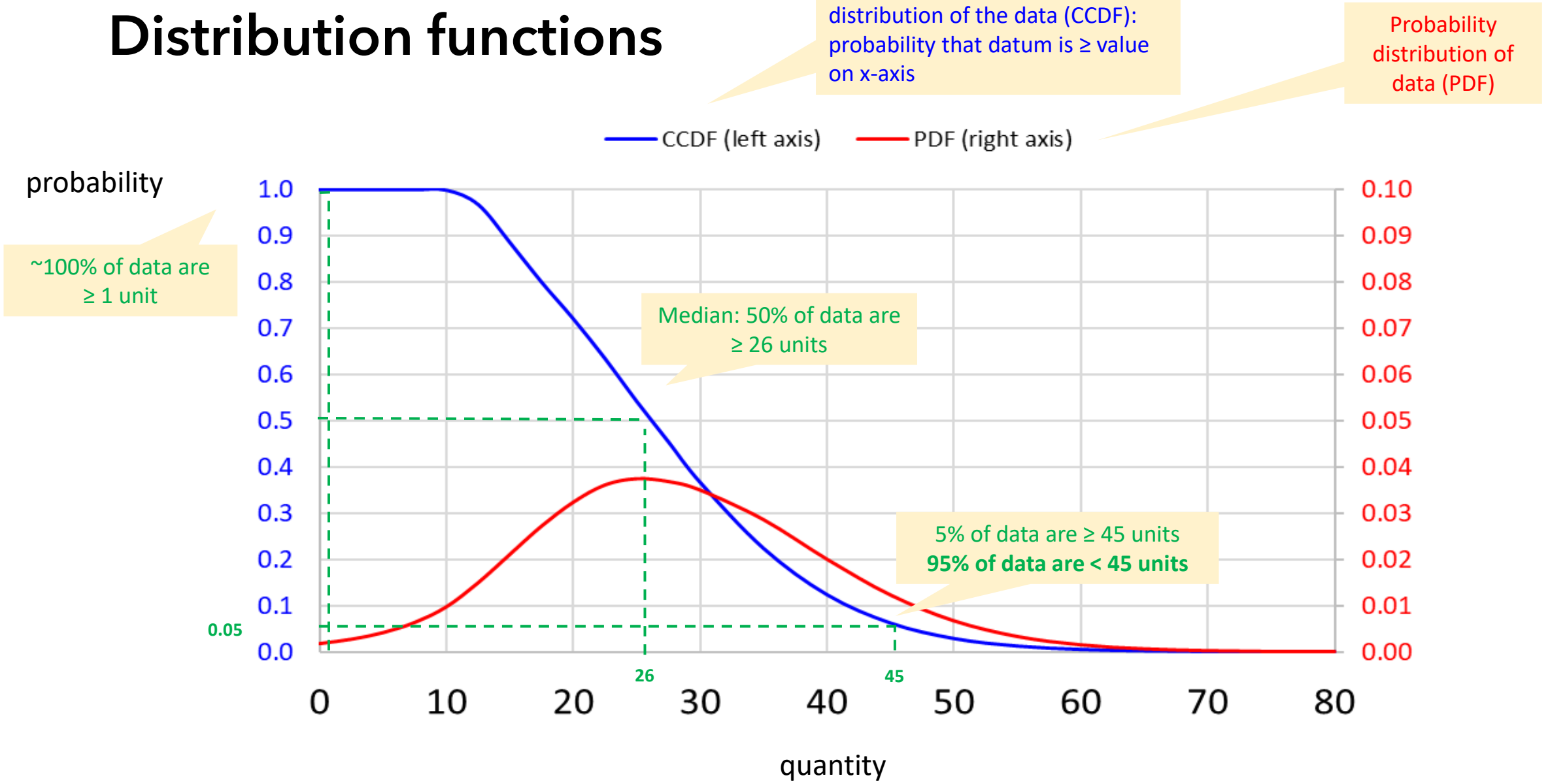
- Current authorisation approaches tend to be based on how much interference a service / equipment can cause, but not how much they should be expected to tolerate. The lack of articulation of how much interference a service or device should be expected to tolerate from services or devices in adjacent bands can cause difficulties when implementing sharing, or when adjacent services change. A common problem is that receivers in a band with a new neighbour are often not good enough to deal with the new radio environment. It may be desirable to explore whether it would be possible to set more explicit expectations about the interference environment, including that receivers should not be so sensitive that they listen acutely to everything in the near radio environment and constrain future evolution of neighbours. Consideration could be given to ways of defining these expectations, including the possibility that receiver performance requirements could evolve into a "Listening Mask". Coexistence should be based on an acceptance of interference between services, and we should work with incumbents that currently expect no interference.
- …"

Source: RSPG Report on European Spectrum Strategy, October 2019

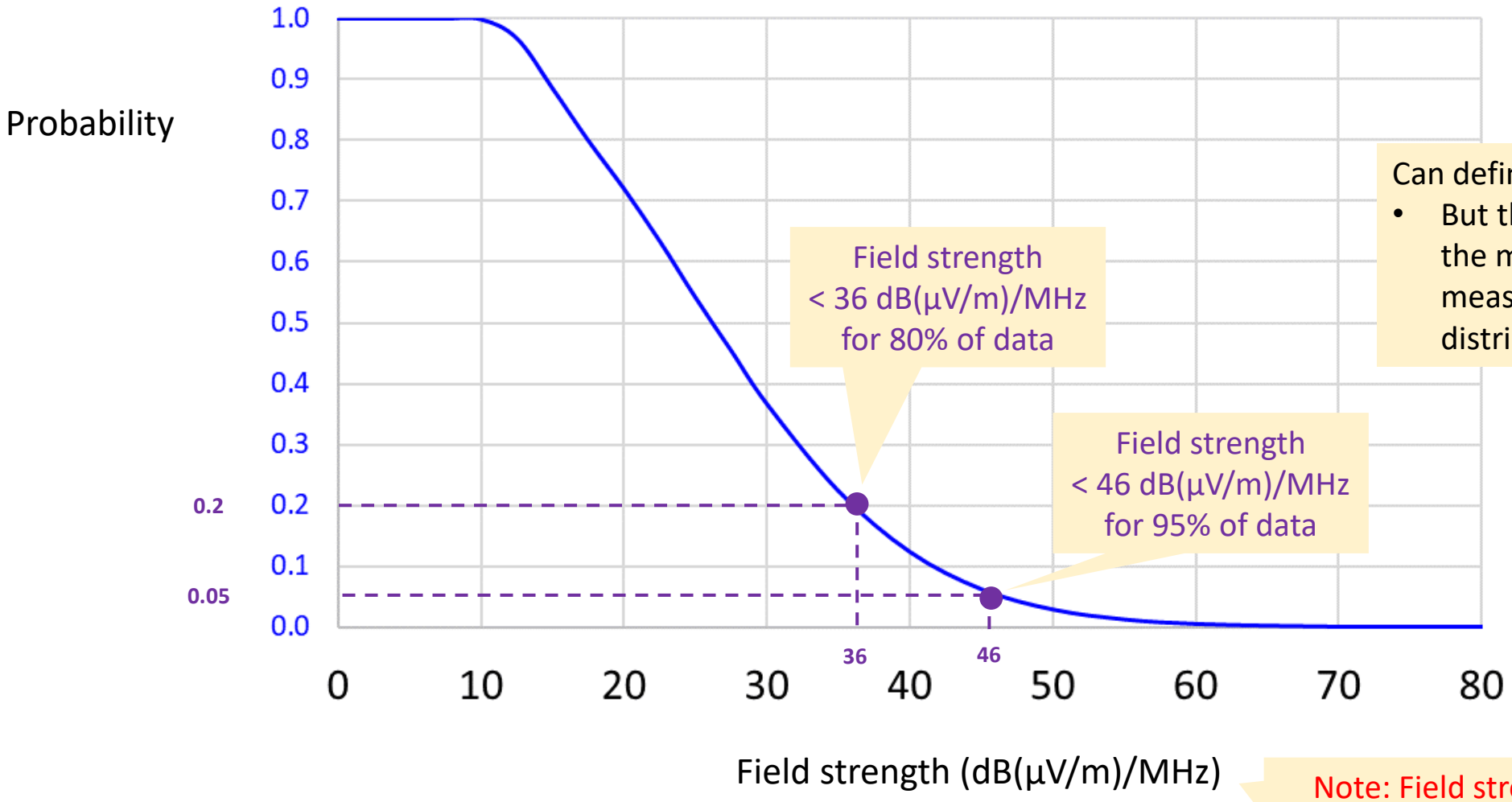
Harm Claim Thresholds
aka Interference Limits

An explicit, up-front statement of the interference that must be exceeded before receiving system can bring a harmful interference claim

Distribution functions



A harm claim threshold uses point(s) on a CCDF



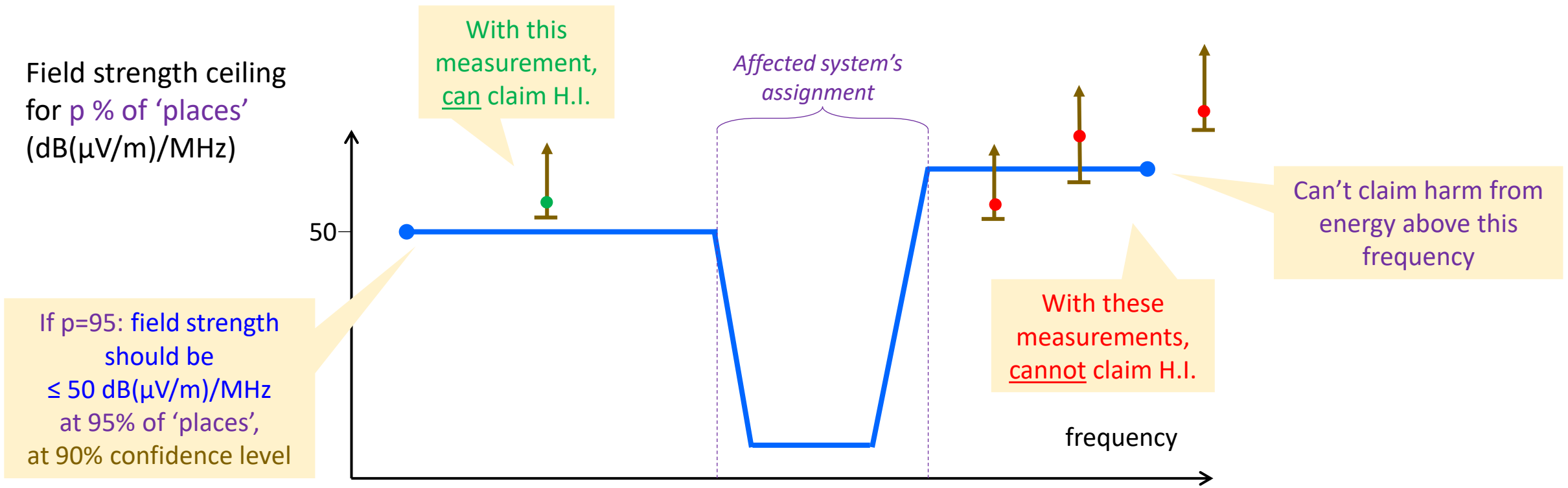
Can define more than one HCT point

- But the higher the percentile, the more difficult the measurement ('tail of the distribution')

Note: Field strength (W/m^2) **not** power (W), which requires antenna assumptions (m^2)

Harm Claim Thresholds

- Operator can deploy any receiver they like, but can't claim harmful interference if neighbor's signal is below the threshold



Benefits of HCT/IL approach

Reduces uncertainty about what interference is harmful

- Readily enforceable harm claim if interference limit exceeded
- Precludes unexpected claims from poor quality receivers

Delegates system design and business decisions to manufacturers and operators

- E.g., receiver sensitivity vs. transmitter density trade-offs

Encourages receiver **performance improvements** without mandating receiver performance levels

- Separates ends and means
- Facilitates system view

Facilitates adjustments at interference boundaries

- Clearer rights means better **bargaining** (cf. Sharkey & Bykowsky 2020)
- Takes fine tuning out of the FCC's hands

Drawbacks of Harm Claim Thresholds

Statistics! 😬

Ex post compliance verification

- Not an *ex ante* bench test

Limits transmitter deployment options

- Interferers can't rely on meeting transmitter power limits in rules

Concept validated in limited number of scenarios so far

- 2D, isotropic, continuous (mid-band cellular)
- (But there's a long literature on measuring RF environment in the field, and much drive test expertise in cellular industry)

What could the TAC do?

Identify high-value band boundaries

- Disparate services on either side
- Likelihood of repurposing in future (i.e., expectation management)

Assess engineering feasibility of specifying environment vs. equipment (aka interference limits vs. receiver standards), incl.

- EU experience with the RED
- RF environment measurement methods
- Inventory (engineering) strengths & weaknesses of each approach

Conclusion

Harm claim thresholds are

- In-band & out-of-band field strength profiles
  not to be exceeded at more than some (small) % of locations
  at some statistical confidence level
  before a system can claim harmful interference

Enable regulators to specify the interference environment in which a wireless system is expected to operate

Incorporate reception in rights definitions without reference to receiver performance

An engineering prior for addressing legal question of harmful interference

Simple to include in rules and measure in the field

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Drill down & Discussion

Some Topics

Establishing and enforcing harm claim thresholds ☛

Yin-yang of spectrum regulation ☛

Relationship to risk assessment?

Where would HCTs have helped?

What about just defining the field strength level a Rx needs to tolerate?

How to assign blame with aggregate interference? Intermod?

Comparison of receiver mandates, harm claim thresholds, and interference temperature? ☛

Drill down:

Establishing and enforcing harm claim thresholds

Establishing Harm Claim Thresholds

To create

- Establish interference caused by existing or anticipated neighbor Tx
  (by measurement and/or modeling)
  - Grandfather in existing adjacent band transmissions
  - Anticipate more intensive use in currently fallow adjacent bands
- Balance equities between Rx and Tx interests
  - Parameters will vary allocation-by-allocation (*not* one-size-fits-all)
- Make rules

Publication ☛

- High-level parameters in regulation
  (e.g., field strength, percentile, confidence level)
- Low-level parameters in ancillary documents
  (e.g., measurement methodologies)

Roll-out

Process in general

- Identify band boundary
- Use multi-stakeholder process to resolve as many issues as possible
  - Costs and benefits for Rx and Tx
  - Rx/Tx trade-offs
  - Parameters and methods (e.g., field strength spectral density, stratification & weighting)
  - Parameter values (e.g., 50 dB(μV/m) per MHz at 2 m)
- Rulemaking as required

Next step

- Identify high-value band boundaries (role for the TAC?)
- Pilot on small scale, e.g., waivers, localized cases

Enforcement

Plaintiff uses measurement and/or modeling to make the case that a harm claim threshold has been exceeded

- Observe and calculate field strength exceedance and confidence interval
- Riihijarvi et al. (2017) propose a method that uses stratification and weighting to ensure fair estimation of statistical confidence and representativeness of field measurements (e.g., drive tests)

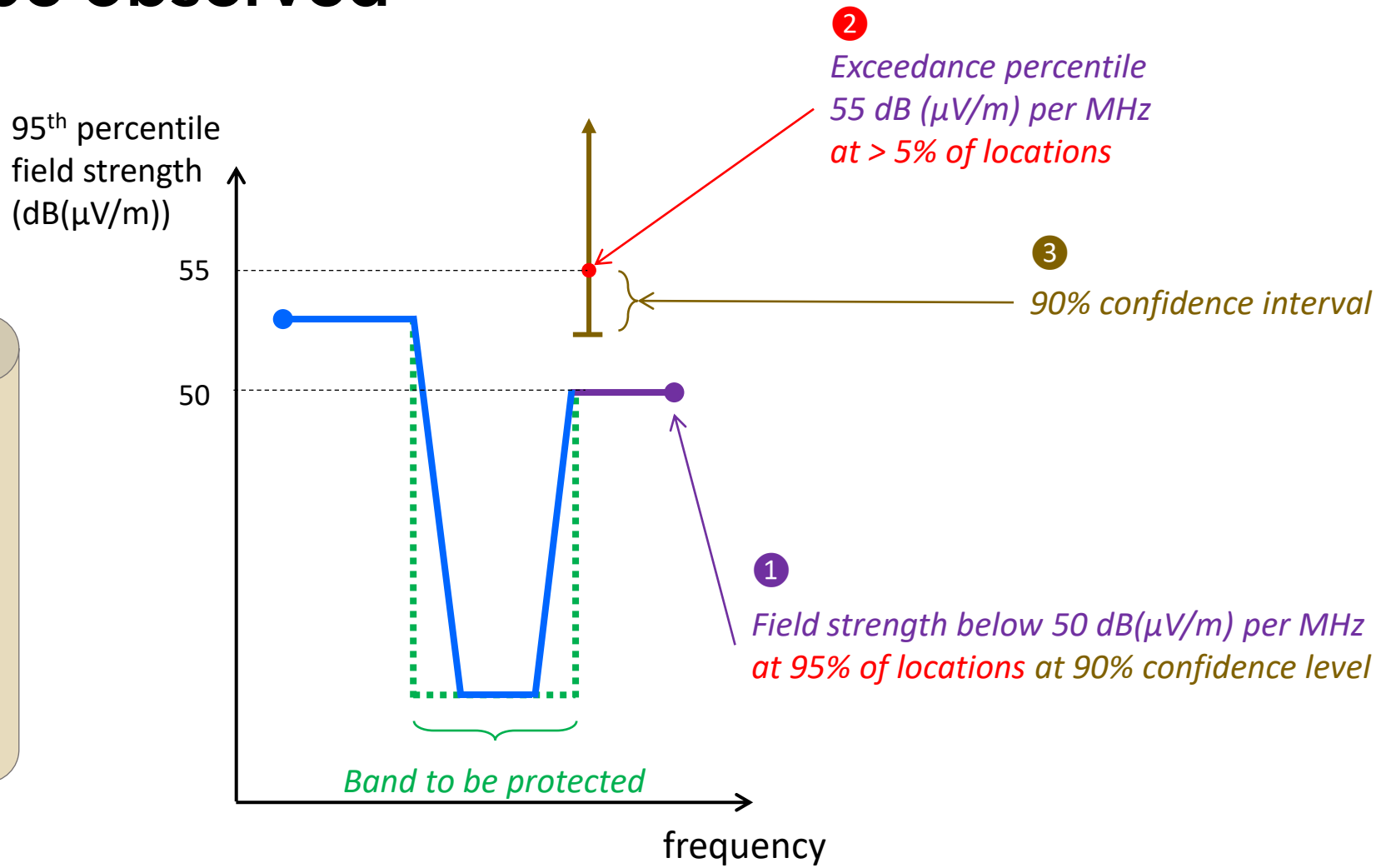
Once a valid harm claim has been lodged, the FCC determines whether there has been harmful interference

Note: neither HCTs nor receiver standards directly address real-time interference response and mitigation

Parameters to be observed

Example HCT:

1. Field strength: 50 dB(μV/m) per MHz
2. Exceedance percentile: 95th percentile (i.e., field strength not exceeded at 95% of locations)
3. Confidence level: 90%



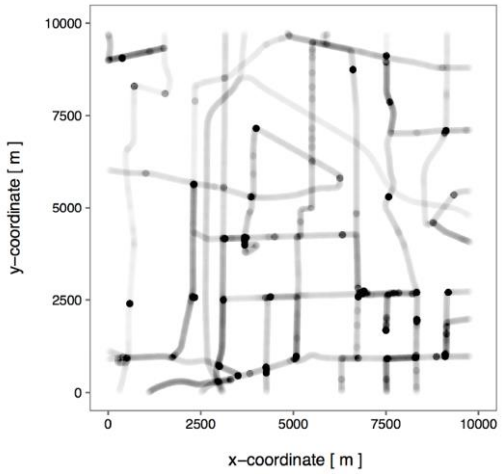
Calculating field strength from a test drive

Stratification: to remove correlated measurement points, enabling fair estimation of statistical confidence

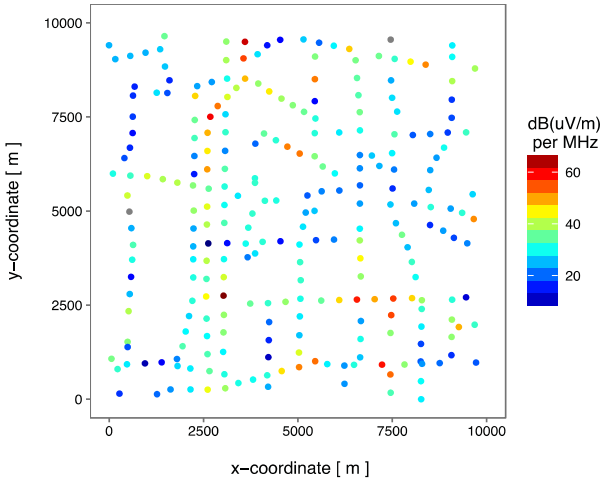
- 260 remaining samples of 65,669 from a 10 km x 10 km region → estimate within 1 dB of ground truth obtained from 4+ million samples

Weighting: ensure representativeness of measurements, giving more value to samples collected from where users are expected to be

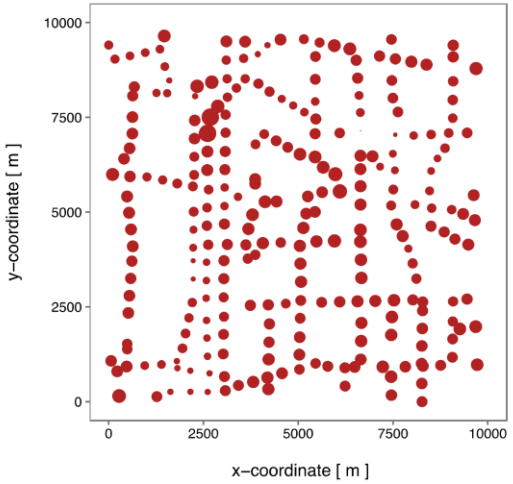
- Population density → 3 dB increase in the estimated field strength at 95th percentile



Drive test data

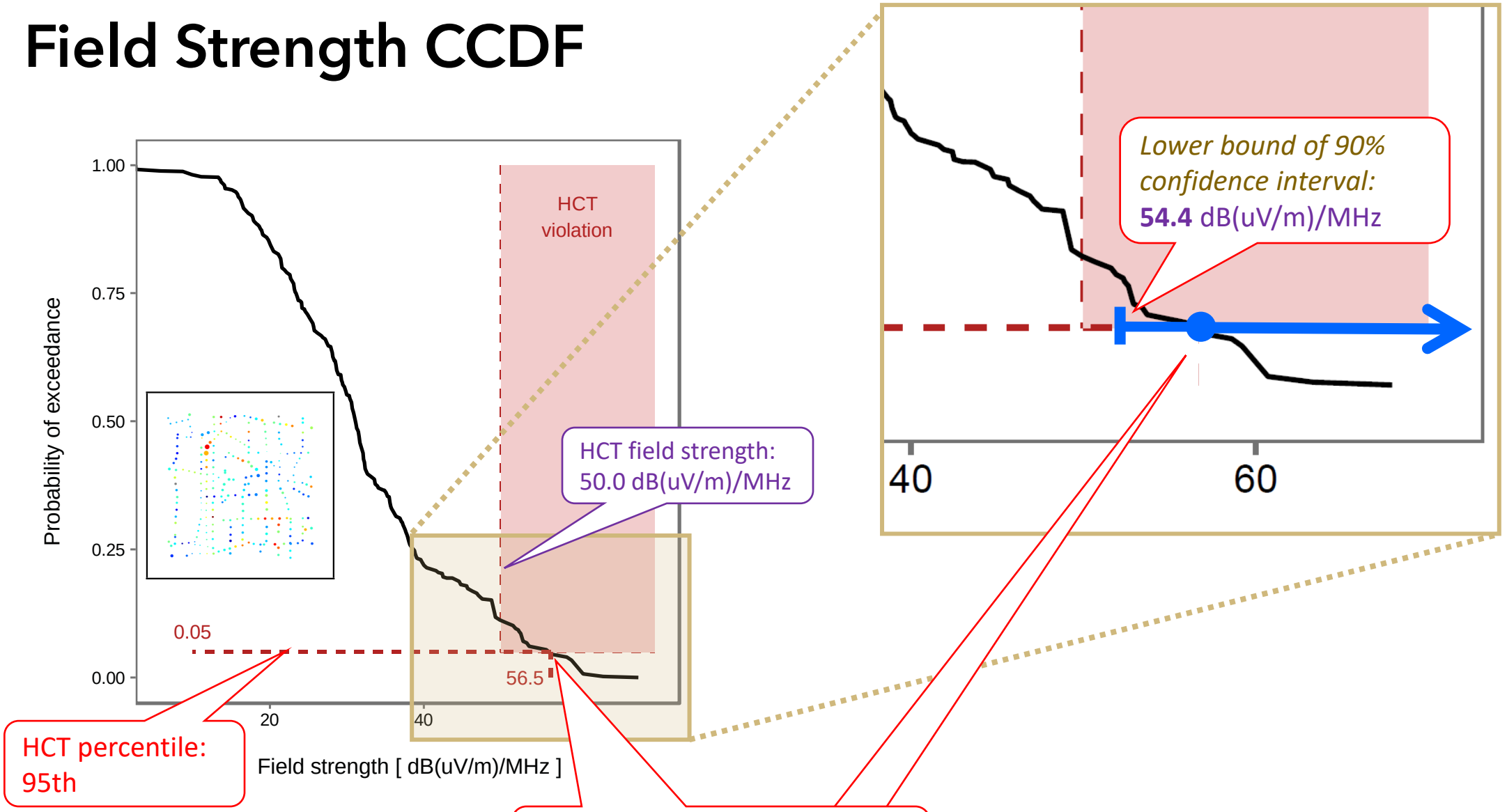


Stratification



Weighting

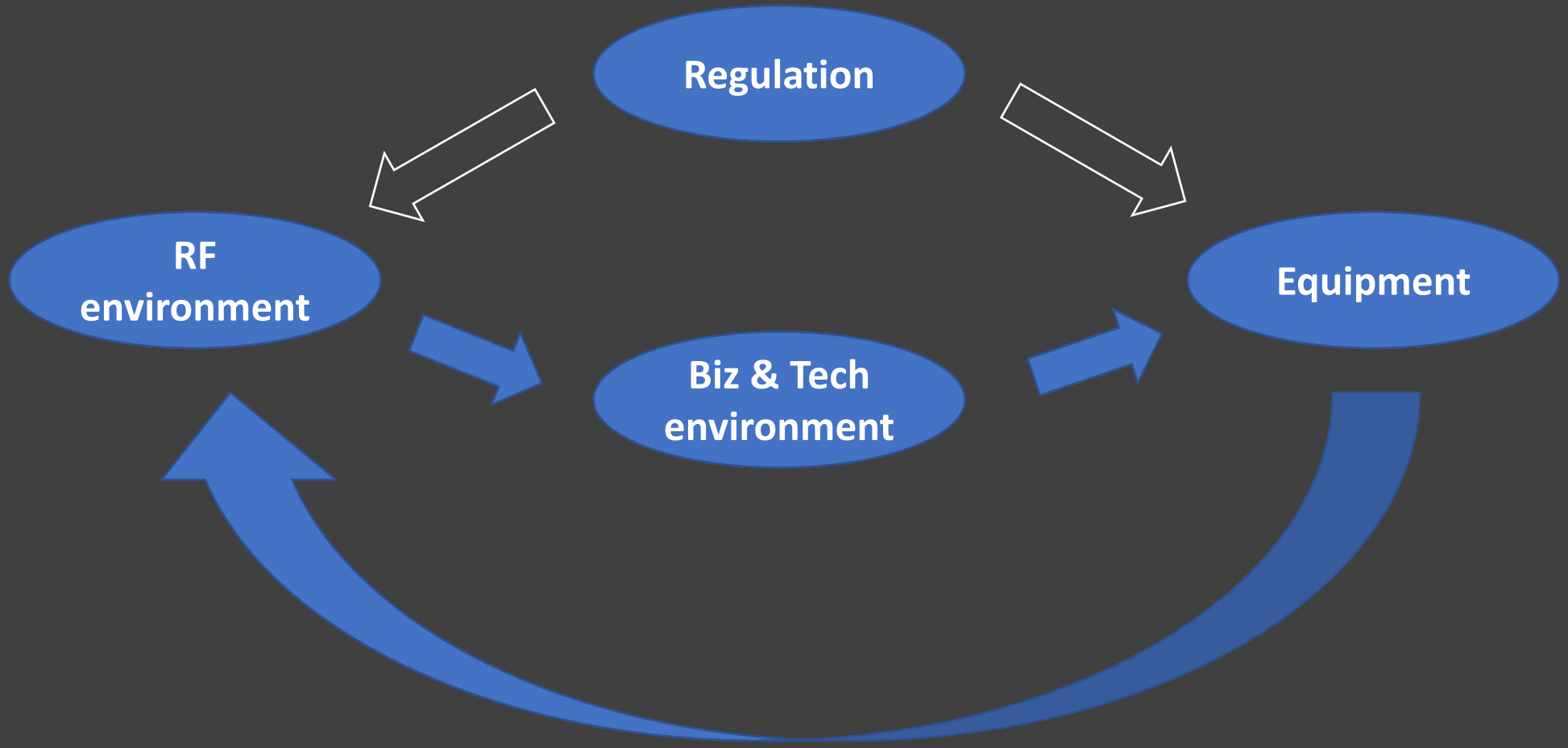
Field Strength CCDF



Drill down:

Yin-Yang of spectrum regulation

Simplified RF design loop



Overflow

What the Regulator Needs to Specify

High-level parameters in regulation

- Unchanging requirements, e.g., broad policy requirements
  - Field strength, percentile and confidence level

Low-level parameters in ancillary documents

- More detailed and dynamic low-level specifications
- E.g., stratification distances, measurement methodologies, via
  - FCC OET Bulletins (cf. E911)
  - Delegation to standards bodies (cf. NTSC, ATSC; ETSI guidance on implementing EU Radio Equipment Directive)

What the Regulator Needs to Specify (Example)

Category	Instrument	Parameters	Example
HCT policy	Regulation (e.g., 47 CFR)	Frequency band	2 GHz
		Percentile of field strength	95^{th}
		Field strength threshold	50 dB(uV/m) per MHz
		Confidence level	90% (α = 0.1)
Measurement procedure	Ancillary documents (e.g., FCC Bulletins)	Stratification procedure	Grid-based
		Weighting method	Population weighting
		Submission of drive data	Complete without gaps
		Responsibility for processing	Claimant
		Requirements on equipment	Standard drive test
Derivation of stratification distance	Ancillary documents (e.g., FCC Bulletins)	Allowed methodologies	Measurements or planning tool data
		Threshold semivariance / autocorrelation	Half of saturation value (or correlation < 0.5)
		Flexibility in model choice	Exponential only

‘Interference Limits’ in an existing standard

“The out-of-band continuous wave (CW) interfering signals can be as high as the levels shown in Figure C-1, measured at the antenna port. . .”

Source: RTCA DO-229D, “Minimum Operational Performance Standards (MOPS) for Global Positioning System/Satellite-Based Augmentation System Airborne Equipment,” Appendix C, “Standard Received Signal and Interference Environment,” Para C.2.1, Out-of-Band Interference

Figure C-1 Interference Levels at the Antenna Port