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Roundtable Report

The Challenges of Radio Spectrum Pollution

June 22, 2023
Washington, D.C.

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In Gratitude

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Table of Contents

Table of Contents 2
I. Introduction 3
II. Session 1: Review and Discussion of the 2013 SFC Conference 4
Presentation Summary 4
Discussion 8
Key Findings 11
III. Session 2 - Impact of RF Pollution 12
Presentation Summary 12
Discussion 16
Key Findings 17
IV. Session 3: Research on RF Pollution 18
Presentation Summary 18
Discussion 19
Key Findings 20
V. Session 4: Enforcement 21
Presentation Summary 21
Discussion 23
Key Findings 24
VI. Session 5: Looking Ahead 26
Presentation Summary 26
Discussion 26
Key Findings 27
VII. Conclusion 28
VIII. Participants 30
IX. Acronyms 31
X. About Silicon Flatirons Center 32
Mission 32
Spectrum Policy Initiative 32
Our Team 32
Our Supporters 32
Publications 32

I. Introduction

On June 22, 2023, Silicon Flatirons convened a roundtable discussion titled "The Challenges of Radio Spectrum Pollution." Hosted by DLA Piper in Washington, D.C, the day-long event asked a diverse group of academics, policymakers, spectrum users, and advocates (see participant list in Section VIII) to revisit topics covered in a 2013 Silicon Flatirons Conference including the current state of noise pollution sensing, the effects of electrification and increased IoT devices on the noise floor, and the difficulties of addressing noise pollution with the Federal Communications Commission's (FCC's) existing regulations and enforcement practices. The roundtable followed up on a public conference convened in 2013 by Silicon Flatirons that explored similar issues.[1] The roundtable discussions took place under the "Chatham House Rule.[2]"

The event opened with an hour-long session refreshing participants on the results of the 2013 Conference on radio frequency (RF) noise pollution.[3]. As each of the takeaways from the 2013 conference were raised, roundtable participants discussed how changes in technology and spectrum uses have altered how they view the topics. The remainder of the roundtable consisted of a series of four moderated sessions. In each session a presenter opened the discussion with a 15-minute icebreaker about the current state of a key issue relating to noise pollution. The subjects covered included the impacts of radio noise pollution, current research practices, enforcement, and a forward-looking assessment about the noise environment.

This report examines each of these roundtable sessions in a separate section. Each section includes a summary of the presentation that introduced the topic, the following discussion by roundtable participants, and the key themes or takeaways from the session. The conclusion section of this report summarizes common themes across the sessions and offers suggestions for further investigation.

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[1] *See* Radio Spectrum Pollution: Facing the Challenge of a Threatened Resource, (John Cook, Megan Coontz Mcallister & Laura Littman, January 31, 2014) https://siliconflatirons.org/wp-content/uploads/2017/06/2013SpectrumConferenceReport.pdf (Silicon Flatirons Center Conference hosted on November 14, 2013) (hereinafter 2013 Conference Report).
[2] Under the Chatham House Rule, participants are free to use the information received, but neither the identity nor the affiliation of the speaker may be revealed. This rule will be modified to allow participants to be quoted in the report, but only with their permission.
[3] 2013 Conference Report

II. Session 1: Review and Discussion of the 2013 SFC Conference

Presentation Summary

Keith Gremban kicked off the roundtable proceedings by delving into the 2013 conference[4], elucidating how a decade of technological advancements has reshaped the environment in relation to RF noise pollution. He offered a concise overview of the conference's keynote address and its four panel discussions, interspersed with valuable insights and remarks from the roundtable participants.

Keynote

In the Conference keynote, Julius Knapp, then Chief of the FCC's Office of Engineering and Technology (OET), presented a comprehensive breakdown of the FCC's provisions for managing RF noise, as they stood in 2013. Knapp organized these provisions into three distinct categories: unlicensed devices, ISM devices (Industrial, Scientific, and Medical Devices), and licensed radio services.

Gremban distilled the 2013 Conference keynote's essence into three fundamental takeaways:

- Addressing the RF noise issue without acquiring quantitative data through systematic means would be extremely challenging.
- There is a critical need for a more precise definition of "harmful interference" to effectively tackle interference-related problems.
- There are fundamental differences between environmental emissions standards and radio noise issues.

Panel 1: Measurements

In the first panel at the 2013 Conference, the importance of establishing a standardized methodology for noise pollution measurement was the dominant topic. While root mean square (RMS) emerged as a universally recognized metric for RF noise, the panel acknowledged that individual observers tend to tailor their measurements to specific criteria, making comparisons between observers' data a challenging endeavor. Consequently, the extent of the noise problem remained uncertain.

To address this predicament, the panel stressed the vital role of comprehensive documentation in the measurement process. While the merits of ex-ante versus ex-post solutions were deliberated, a consensus emerged that additional measurements were imperative before enforcement strategies could be devised. Furthermore, panelists unanimously concurred on the significance of aggregating emissions data and advocated for

> *"Does it take one more transmitter to break the camel's back and create harmful interference? How do we measure this? How do we characterize that?"*

[4] *Id.*

greater transparency among carriers in sharing their existing data resources.

Panel 2: Services and Scenarios

The second panel at the 2013 conference delved into the various manifestations and levels of noise pollution encountered by service providers and other users in practical scenarios. In 2013, there was widespread acknowledgment of increasing RF noise pollution, and an inability to quantify it due to inconsistent and unreliable measurements. The panel touched on many issues facing unlicensed users, especially the necessity of replacing the existing "honor system" for operating in such bands with something more sustainable.

> *"We need these systematic, transparent, and scientifically based measurements [for] cost-benefit analysis to inform standards and to characterize the problem."*

Finally, while incumbents believed they had a right to free and clear link margins, the realities of spectrum sharing meant that aggregation of RF noise from many transmitters would be a problem for incumbents. Solutions presented in this panel included: deployment management, receiver performance standards, harm claim threshold regulations, case-by-case approaches to regulation, and involving the private sector in interference standards and regulation.

Panel 3: Lessons from Environmental Pollution

The 2013 Conference's third panel spotlighted the efficacy of market-driven incentives, reminiscent of Coase's principle.[5] It was posited that these principles could prove more effective than punitive measures like taxation or fines. Additionally, the discussion touched upon the possibility of applying a cap-and-trade model to address spectrum pollution, similar to the system used for environmental pollution. Once again, the conversation underscored the indispensable need for standardized measurements and disclosures to enhance the viability of such approaches. Ultimately, the panel concluded that environmental models might not seamlessly translate to the realm of RF spectrum issues, largely due to the more tangible consequences of environmental pollution and the relative ease of assigning blame.

Panel 4: Enforcement and Policy Initiatives.

The final panel highlighted a noteworthy revelation: RF noise might not be the foremost concern in unlicensed bands; rather, the predominant issue could be the competition among users for access to channels. The lack of a scientific approach to RF noise pollution interference were laid bare, accentuating the anecdotal nature of complaints and the dearth of publicly available data. The panel also emphasized the disparity in resources, with the Commission's 1742 total employees making up only a

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[5] Coase's theorem posits that as long as property rights are well defined, the party with the greatest economic gain will have an incentive to pay other parties not to interfere or pollute. If property rights (or the "harmful interference" standard for RF spectrum) are specifically defined, transaction costs will be lowered. The party with the greatest economic incentives will pay those it is harming not to interfere with their actions. Applied to environmental pollution, a polluter may value the way they do business to the degree that paying harmed parties in order to continue as they have been economically viable. *See* R. H. Coase, *The Problem of Social Cost,* 3 J.L. & Econ., 1 (1960); *See also* 2013 Conference Report.

fraction of the Environmental Protection Agency's (EPA's) 7,172 person science-focused workforce.[6] Lastly, the panel arrived at the conclusion that unintentional radiators[7] represent the most significant contributors to the noise floor, though the absence of quantitative data to substantiate this claim was underscored.

In the takeaways slide at the roundtable, Gremban distilled the key overarching themes that emerged from the 2013 conference:

- There is strong evidence that the noise floor is rising in increasingly higher frequency bands;
- There is a need for systematic, transparent, and scientific measurement;
- The increase in noise pollution matters, as shown by carriers valuing 600 MHz spectrum less than 700 MHz;
- The current resources being put toward the problem are insufficient;
- Environmental models may not translate well to the spectrum environment;
- Non-intentional radiators are the biggest contributors to the noise floor.

Now vs. Then.

Gremban turned the presentation to examine how the RF noise pollution landscape evolved over the past decade due to rapid technological progress. Notably, it underscored the shifts in wireless connectivity, where the use of wireless as the primary means to access the internet has surged from a mere 3% in 2013 to a staggering 97% of connections today, as illustrated in Figure 1. This transformation has been accompanied by an exponential increase in connected wireless devices and the burgeoning practice of RF spectrum sharing.[8]

[6] "Federal Communications Commission Workforce Composition." https://www.eeoc.gov/federal-sector/federal-communications-commission-fcc EPA: 17,202 total employees. 7,172 focused Environmental Protection, Environmental Engineering, and General Physical Science. "Environmental Protection Agency Workforce Composition." https://www.eeoc.gov/federal-sector/environmental-protection-agency-epa-0.
[7] Unintentional radiators include devices that generate RF energy for use within the device without the intention to emit RF energy by radiation or induction. Examples consistently raised in the roundtable included electric vehicles and their charging stations, but anything that uses RF energy emits some form of unintentional radio waves (see 47 CFR 15.3(z)).
[8] *Id.*

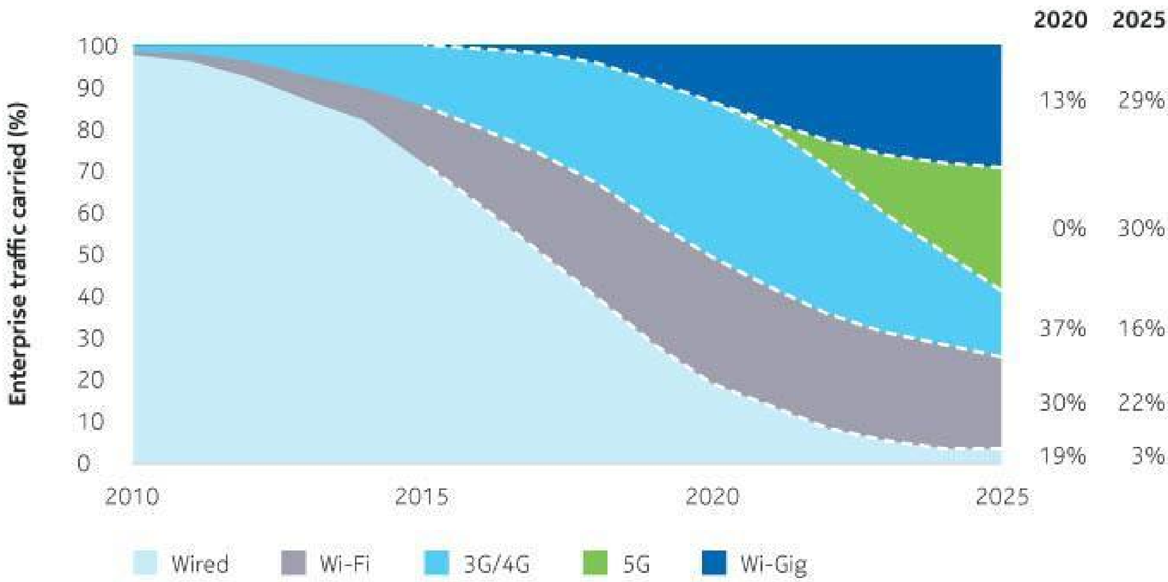

Figure 1: This figure depicts the shift from over 95% wired connections in 2010 to today where 97% of connections are wireless. (source: M. K. Weldon, The Future Network: A Bell Labs Perspective (2016))

With a focus on the proliferation of wireless devices, Gremban voiced apprehensions about the sheer volume of the Internet of Things (IoT) devices and their potential to strain wireless capacity as they transmit vast quantities of data. Figure 2 illustrates the projected growth in the number of connected devices per household. While the graph projects over 50 devices by 2023, some participants asserted that their households have over 75, making the projection somewhat conservative. Adding to this concern, he highlighted the impact of unintentional radiators, particularly in the form of alternative energy sources, electric vehicles (EVs), and EV infrastructure like charging stations, which hold the potential to drastically reshape the RF environment.

Gremban concluded by presenting several pertinent questions for the roundtable's consideration:

- Have there been significant advancements in characterizing and measuring noise?
- What kinds of noise are participants encountering in real-world scenarios, and do they possess comprehensive data to substantiate their observations?
- What enforcement tools are at our disposal, and should our focus be on preemptive (ex-ante) or post-event (ex-post) techniques?
- Lastly, he proposed the idea of whether Silicon Flatirons should host another conference dedicated to addressing these critical questions.

Discussion

After Gremban finished each of his slides various participants raised issues and spoke on how the spectrum environment has changed since the 2013 Conference.

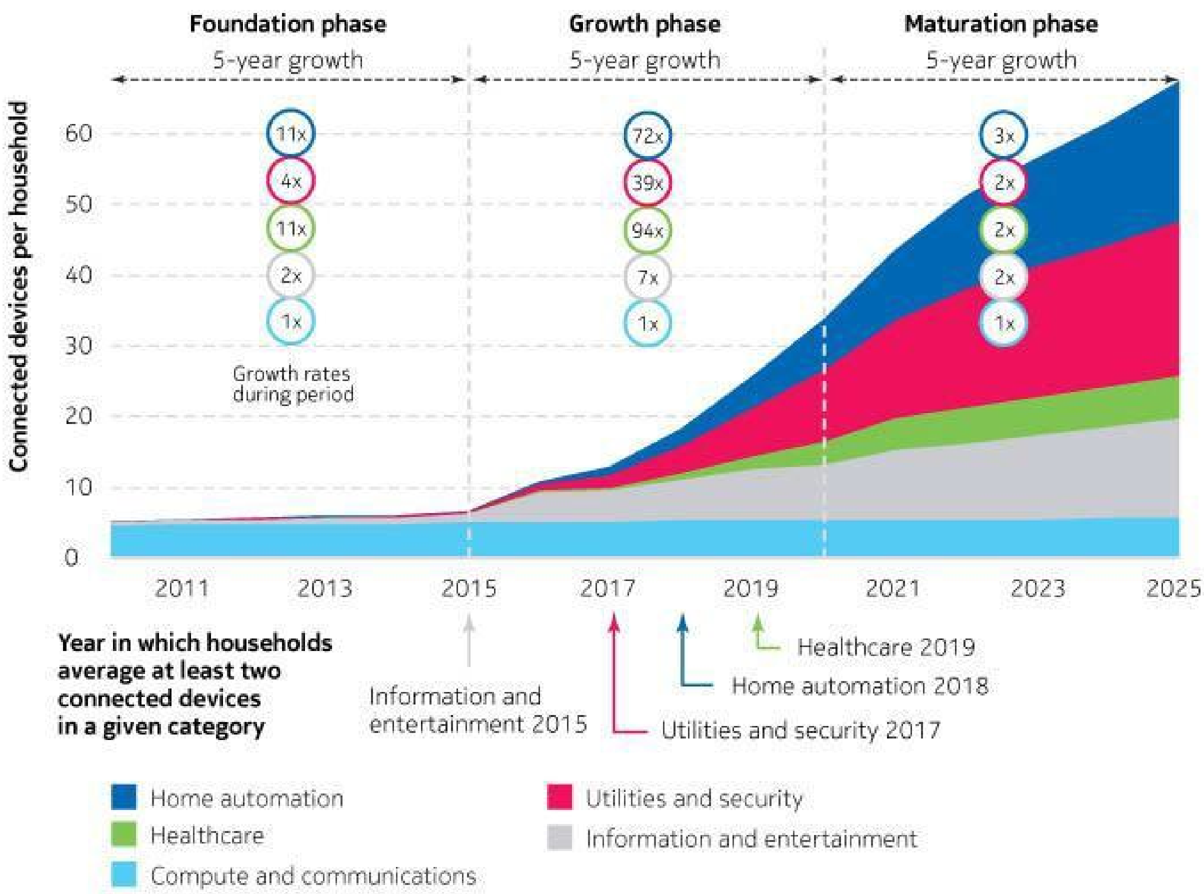

Figure 2: This figure shows the increase in the average number of connected devices per household increasing from around seven at the time of the 2013 Conference, to over fifty in 2023. (source: M. K. Weldon, The Future Network: A Bell Labs Perspective (2016))

Defining RF Noise Pollution

Participants debated the definition of RF noise pollution. While the 2013 conference report defined RF noise pollution as "radio frequency interference that does not come from an identifiable, intentional radiator," participants in 2023 were far less comfortable limiting the definition to only unidentifiable, unintentional radiators.

> *"There's a regulatory challenge [here] if we're going to move forward in this area, we should pick a definition that doesn't have… observer dependence to it."*

Participants raised several concerns regarding the existing definition. First, it did not adequately account for the significant increase in RF spectrum sharing, especially in government spectrum. Some participants argued this sharing increase had led to a surge in aggregate emissions. This growth had contributed to raising the noise floor through identifiable, intentionally emitting co-channel users. Some participants argued against including shared bands, like the Citizens Broadband Radio Service (CBRS), contending that these uses relied on meticulous coexistence studies and advanced planning.

Second, participants questioned including the notion of identifiability in the definition, highlighting that different equipment would allow for very different results in identifying noise sources. As one participant pointed out, "What I can't identify using a $20 dongle, the NSA could probably identify with a very sensitive piece of equipment." Such subjectivity in the definition was seen as problematic for regulatory purposes.

Nonetheless, others argued that regulators and affected parties dealt differently with identifiable and unidentifiable interference. Known radiators were deemed easier to address than the nebulous realm of unknown RF noise pollution.

Additionally, a concern was raised about receivers generating internal noise, emphasizing the importance of accounting for this noise when developing standards for measuring noise pollution.

Although the debate over the definition persisted throughout the session, it became evident that the more comprehensive definitions were favored. This seemed to acknowledge the diverse sources of RF noise, especially from the proliferation of IoT devices. However, the roundtable did not settle on a concrete definition, leaving this task as an essential next step.

> *"I think I can ask anybody in the room, is radio noise increasing? And the answer would be, yes. …OK, by how much? What's the rate of increase? How bad is it, and does anybody have an answer for that?"*

Reliance on Anecdotal Evidence

The session focused on the critical need for standardization in measuring and categorizing RF noise pollution. Participants shared a consensus that RF noise was on the rise, but these observations relied heavily on anecdotal evidence and inconsistent measurements. This lack of standardized data hindered the ability of academics and researchers to replicate or study these experiences systematically. The questions remained:

- How much is RF noise increasing?
- What is the rate of increase?
- How severe is the issue?
- How can noise generated by receivers through internal electrical components be accounted for?

Finding answers to these questions through standardized measures and methodologies emerged as a pressing concern.

Participants shared anecdotes that shed light on the impact of RF noise pollution in various contexts. For instance, one participant related an incidence of RF noise pollution affecting military communications in Iraq. In this instance, a facility in a small valley, initially populated by 7,000 people, experienced rapid population growth to over 35,000. As the population surged, the military had to adapt its radar and communication systems due to the rising RF noise floor, which became noticeable around the 15,000-population mark.

Another anecdotal example involved suburban expansion along Highway 14 in California, encroaching upon Edwards Air Force Base. As the suburban area expanded closer to the base, the RF noise pollution increased. These real-world cases helped contextualize the issue, making it tangible. However, the absence of standardized RF noise pollution measurements prevented third-party analyses or applications to other situations.

Participants also highlighted the possibility that the lack of standardized measurements might result from entities being overly proprietary with their data. For instance, wireless carriers possess valuable interference modeling experience. Some participants suggested that sharing and harmonizing such data with researchers could yield valuable insights.

"The lack of reporting on interference should not be taken as a lack of any sort of interference events, caused by noise or otherwise."

Finally, one participant voiced concerns about relying on anecdotal measurements, which could create opportunities for bad actors to engage in "insidious contamination" of scientific measurements in passive bands such as those conducting radio astronomy. The speaker outlined three types of contamination: (1) low interference, which is inconsequential; (2) strong contamination from another source, leading to the rejection of measurements; and (3) insidious contamination, where a bad actor artificially creates RF noise incrementally in a way that appears to researchers to be genuine measurements. The concern was that without standardized assessment methods for RF noise pollution, such actors could exploit insidious contamination to produce false readings that scientists might mistake for genuine phenomena.

Enforcement Challenges

The theme of enforcement challenges recurred throughout the session, emphasizing the difficulties in pursuing interference enforcement actions. Participants underscored the complexity of initiating an enforcement action, with one stating that "people [don't] appreciate how difficult it is to take an enforcement action."

One speaker drew a comparison between enforcing a speeding ticket and enforcing an interference action. Violating a traffic rule results in a straightforward ticket or mail notification, with limited options for appeal. In contrast, FCC enforcement actions entail a multi-step process, involving a Notice of Apparent Liability, opportunities for response, interim staff meetings, and sometimes the development of comprehensive programs to prevent future violations. This process was highlighted for its resource-intensive nature.

Furthermore, participants stressed that for aggregate RF noise pollution issues, this already demanding enforcement process would become even more difficult. If the RF noise comes from a single source, this is relatively easy to identify. However, if the issue is due to the aggregation of multiple sources, it is much more complex to identify the contributions. This identification step would need to be completed before the resource-intensive enforcement process could even begin. The absence of standardized data sources and methodologies for measuring noise pollution further exacerbated these difficulties.

Participants highlighted the challenges associated with the current case-by-case enforcement system. Many RF noise-related issues go unnoticed by the FCC because operators often opt to tolerate a certain level of RF noise pollution and adapt to it rather than initiating resource-intensive enforcement actions. One participant emphasized this point by noting that "the lack of reporting on interference should not be taken as a lack of any sort of interference events, caused by noise or otherwise." Another commenter added that even if an operator prevails in such an action, they "never win a spectrum battle. You buy time. You win time. It'll be back, and the challenge will always be there."

Some participants explored the challenges of ex-ante (preemptive) approaches, which present their own complexities distinct from ex-post (reactive) enforcement. One participant raised the question of how to incentivize receiver designers to implement noise-reducing techniques. They posed a query for future research: How do you promote low-noise design practices if the designers have no incentive to implement these changes? Although participants expressed skepticism about the transformative power of either form of enforcement, the consensus leaned toward tackling the issue from multiple angles.

An alternative approach to enforcement, termed "jaw boning," was also raised. This method would involve high-ranking officials, such as the FCC chair or even the President, publicly addressing and condemning bad actors responsible for increasing the RF noise floor. By drawing attention to such behavior, the government could incentivize more responsible actions without navigating the complexities of traditional enforcement approaches. However, this strategy would necessitate clear data pinpointing the actors engaging in harmful behavior. The availability of such data hinges on increased data sharing and the establishment of standard methods for measuring RF noise pollution. Furthermore, this approach would rely on enhancing public understanding of the spectrum and how polluting devices might affect people's lives.

Comparisons Between Environmental Pollution and RF Pollution

Participants raised the contrast in visibility to the public between spectrum pollution and environmental pollution. Spectrum pollution is considerably less visible, making it challenging to galvanize public sentiment for government action or to shame polluters into changing their practices in the RF environment. One participant's example vividly illustrated this point. In a community where many individuals suffer from lung issues, they can readily connect their symptoms to smoke emitted by a factory. However, attributing a dropped call to the proliferation of IoT devices increasing the RF noise floor is far more complex.

Another participant pointed out that as more people become reliant on wireless devices, wireless issues are gradually becoming more apparent to the public. They argued that improving the public's ability to link dropped calls or internet disruptions to specific causes could lead to successes akin to those achieved in more readily attributable cases of environmental

> *"Spectrum pollution is less visible to the public, and I think that is a real issue. You can see the smoke coming out of the smokestack."*

pollution. While this discussion began during this session, it continued throughout the roundtable.

Key Findings

In evaluating the difference between RF noise pollution issues in 2013 and 2023, the session produced several key findings.

- The standardization of methods for measuring RF noise pollution is a prerequisite for any action taken to address RF noise pollution.
- The 2013 Conference's definition needs to be replaced by one that takes into account intentional radiators due to the proliferation of IoT devices in the past 10 years.
- Action is needed to make the results of RF noise pollution more attributable for the general public.
- The lack of standardized methods for measuring RF noise pollution and the arduousness of the FCC enforcement process are significant barriers that need to be addressed.

III. Session 2 - Impact of RF Pollution

Presentation Summary

Session 2 of the roundtable commenced with a presentation titled "VHF is Dead,"[9] delivered by Joe Blaschka of CEJA Engineering. Blaschka provided a comprehensive understanding of the issue at hand and proceeded to delve into test results, culminating in a set of enlightening conclusions.

Blaschka opened his presentation by summarizing the significance of increasing RF noise levels as a pressing concern. He detailed the pivotal concept that for any system to function optimally, the desired signal must remain distinguishable from other signals within the geographic area. From the receiver's perspective, all surrounding signals are classified as undesired and thus collectively constitute RF noise. RF noise can emanate from various sources, including internal sources within the receiver itself, thermal noise, as well as external ambient sources. As ambient RF noise levels escalate, the overall ambient RF noise floor rises.[10] This elevation in ambient RF noise levels results in a decline in the signal-to-noise ratio which means that the system may not function adequately.[11] This can be a public safety issue for groups relying on their radio signal like the fire department or law enforcement. To counteract the challenges posed by a heightened ambient RF noise floor while maintaining the desired performance, a transmitter must transmit at higher power or more transmitters must be added.

Blaschka proceeded to describe his test setup and shared key findings. The test configuration was designed to mirror the characteristics of land mobile receivers. Blaschka selected this test configuration because he was working to assist users of land mobile communication systems.[12]

Blaschka found that every location he tested had at least some ambient RF noise in VHF frequencies. Typically land mobile systems are designed to operate with desired signal RF levels around -109 dBm or possibly up to -105 dBm using 10 kHz of bandwidth.[13] The lowest RF noise areas measured a noise floor typically between -115 and -112 dBm. Suburban areas tested at a RF noise floor varying between -110 and -100 dBm while urban areas were generally very noisy up to -85 dBm. This is significantly more RF noise than the systems were designed to accommodate resulting in unusable desired signal levels.

Blaschka made measurements of RF noise with 10 kHz resolution bandwith, as illustrated in Figures 3-7. In the figures, two lines indicate noise levels. The "Measured"

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[9] VHF (Very High Frequency) comprises the frequency range 30 - 300 MHz.

[10] The RF noise floor is an aggregate measurement of all the signals in an environment. This RF noise floor or RF noise environment is one that the transmitter and receiver pair must overcome in order successfully pass the desired data.

[11] A decrease in signal-to-noise ratio can lead to problems with receiving the desired data. In a voice radio, this appears as dropouts or lack of clarity in the sound. For data transmissions, low signal-to-noise ratio can cause low data throughput or loss of data all together.

[12] Land mobile receivers are communications systems often employed by government workers, emergency responders, work sites, and the military. The systems are mainly used for voice communications but can support low speed data.

[13] Note, using the dBm unit as a measure of signal power means that the more negative numbers indicate a quieter signal. For example, -115 dBm is lower power than -112 dBm.

line denotes the measured value, while the "Actual" line is the measured value with system losses added back in.

Commercial activities in particular resulted in increased ambient RF noise near the stores. Blaschka noted that significant RF noise could be detected in certain environments, such as near semi-trucks and store entrances. Blaschka further noted that some in-building systems (like LED lighting systems) could produce significant RF noise.

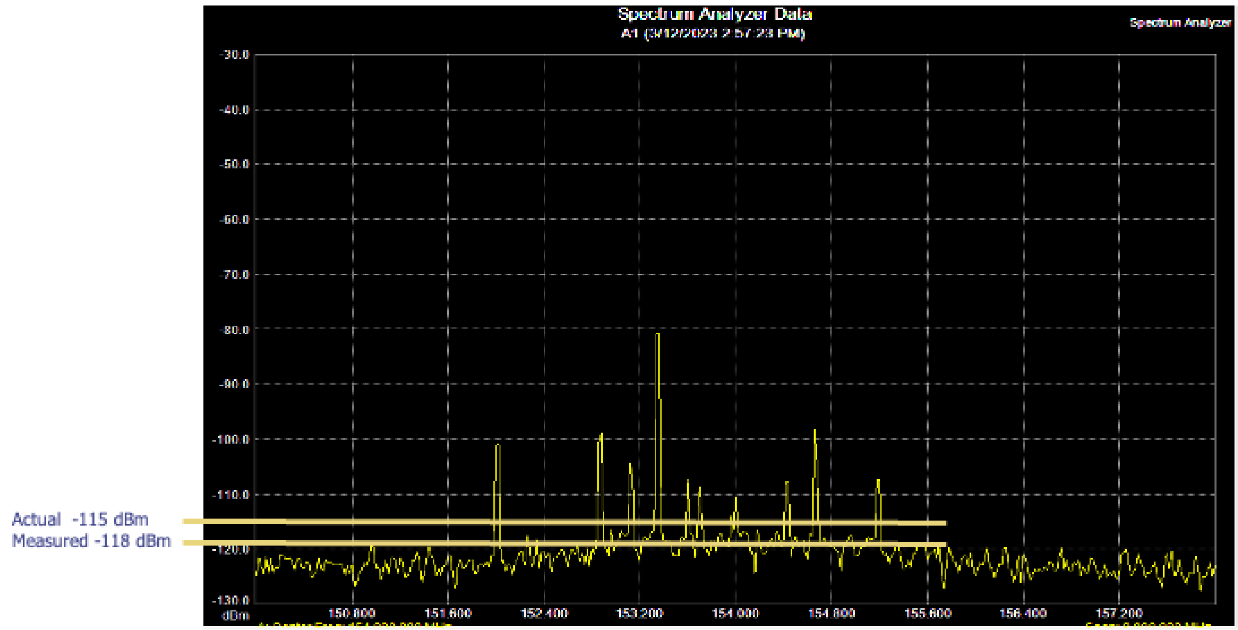

Figure 3: This measurement was taken in a residential area with large lots and older homes. The apparent RF noise floor of -115 dBm per 10 kHz is exceptionally low. (source: J. Blaschka)

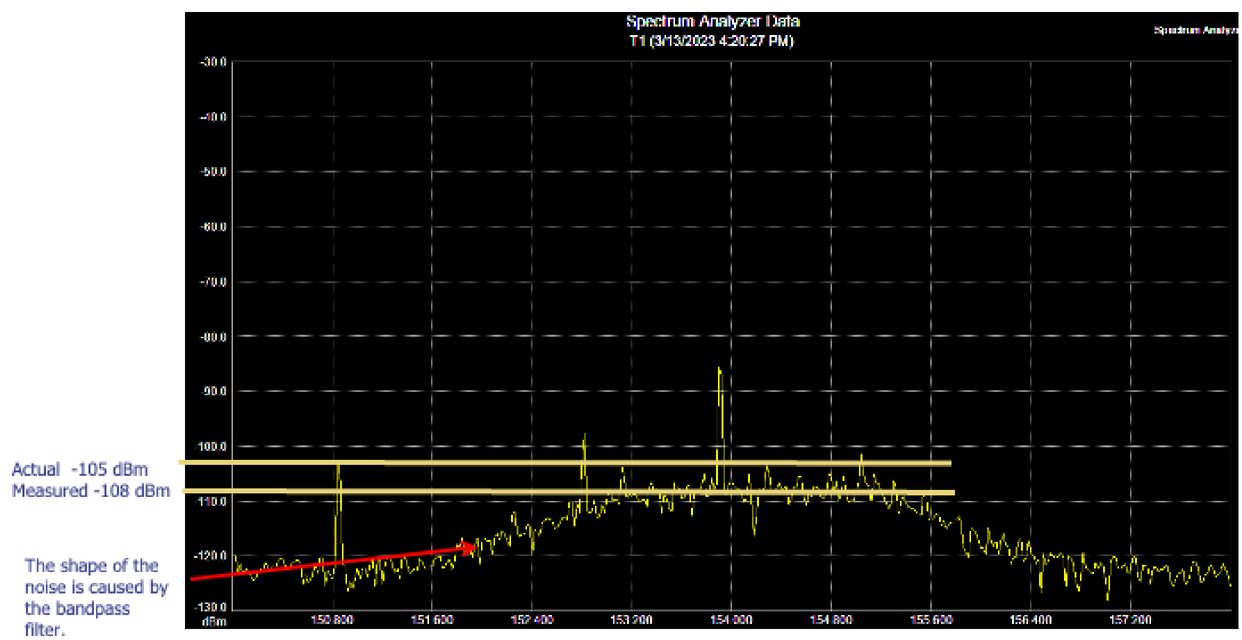

Figure 4: A measurement taken in a second residential area near the first shows significantly higher RF noise– as much as 105 dBm per 10 kHz. These values would result in a "fairly significant loss of coverage." (source: J. Blaschka)

Blaschka underscored that such heightened levels of RF noise pollution detrimentally impacted users' ability to receive signals effectively. Amplifying transmission power to combat this challenge is not a viable long-term solution, as it would trigger a never-ending cycle of users needing to transmit at higher power to outdo one another, thereby perpetuating the escalation of RF noise levels.[14]

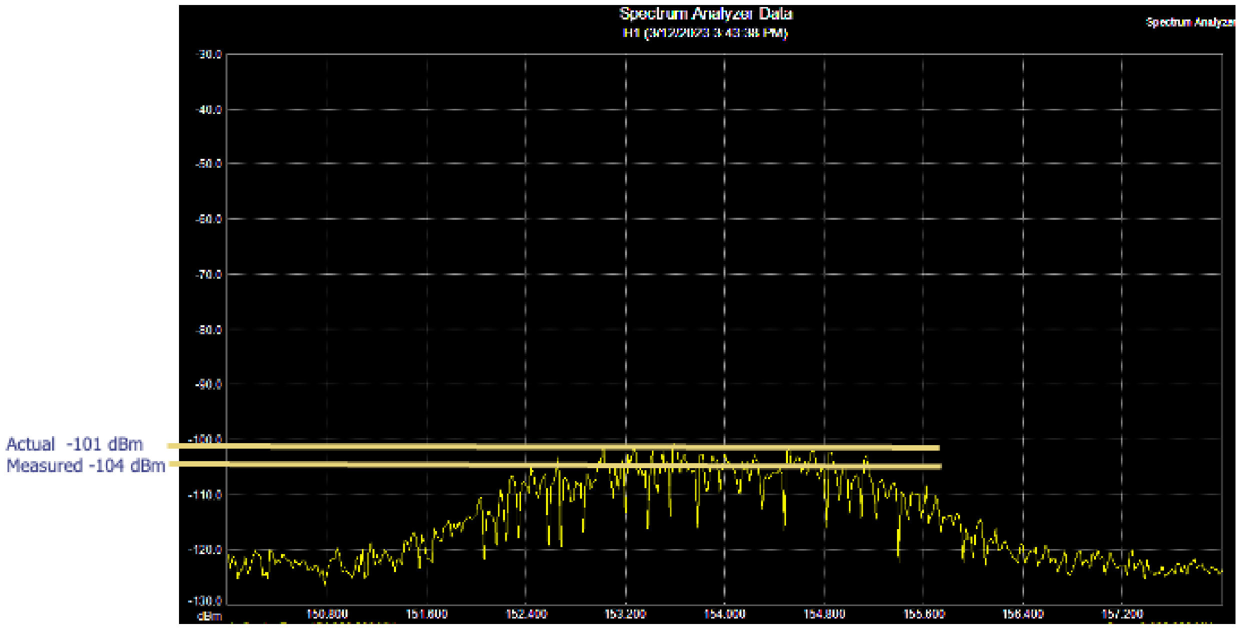

Figure 5: This measurement was taken on a small town, main street outside a yogurt shop. Some sources in the area are causing a high level of RF noise. This could cause degraded performance for users of land mobile receivers, like law enforcement. (source: J. Blaschka)

> *"The increased noise floor at VHF where the users operate can and does affect the user's ability to receive."*

Finally, Blaschka highlighted a pivotal shift in the design considerations between VHF and 800 MHz frequencies. While VHF was once a superior choice, the mounting RF noise levels within the VHF spectrum have prompted reconsideration. 800 MHz is now a potentially more suitable alternative, since there is less RF noise level increase around 800 MHz. However, Blaschka acknowledged that transitioning to 800 MHz may not be a feasible option for all systems.

To find effective solutions, a consensus must first be reached, acknowledging the substantial challenge posed by the high RF noise floor. Then concerted efforts must be dedicated to identifying and addressing the root causes of this pervasive issue.

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[14] This issue is often referred to as the "cocktail party problem." As more guests join the party, the noise goes up. Then people need to talk louder to overcome the din, which forces other conversationalists to speak at an even greater volume. The noise level spirals upwards.

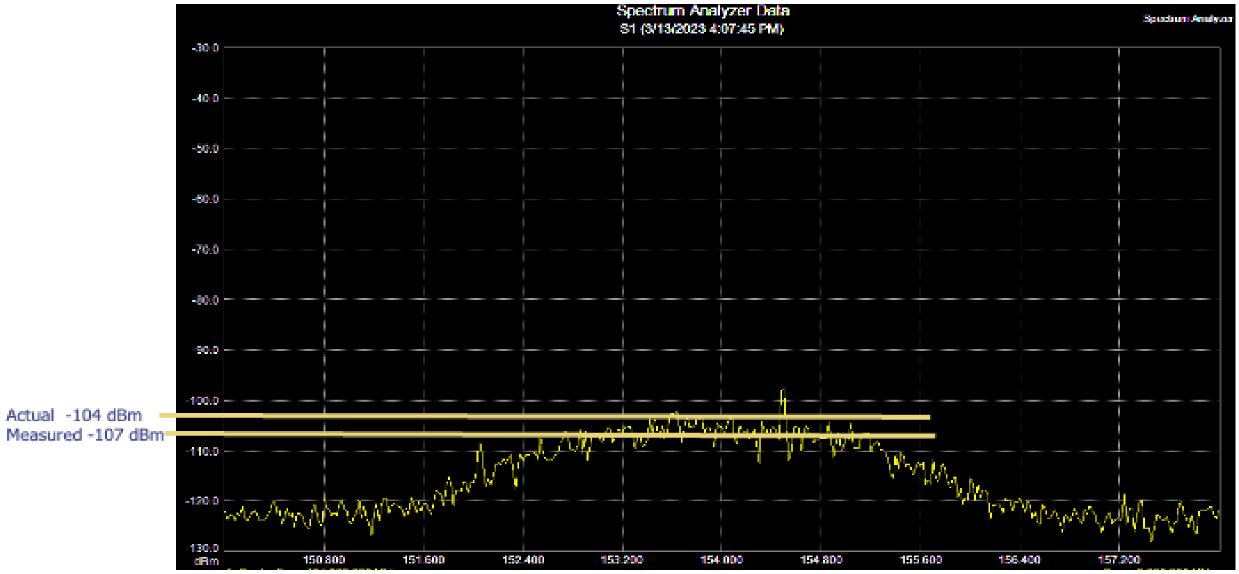

Figure 6: This measurement was taken in an apartment building's partially underground parking garage and shows a high amount of RF noise. Some of the sources could have included LED lights, an alarm panel, or building controls. An environment like this would make it difficult for the fire department to communicate due to the difficulty of external signals making it into the partially buried structure and due to the RF noise coming from inside the garage itself. (source: J. Blaschka)

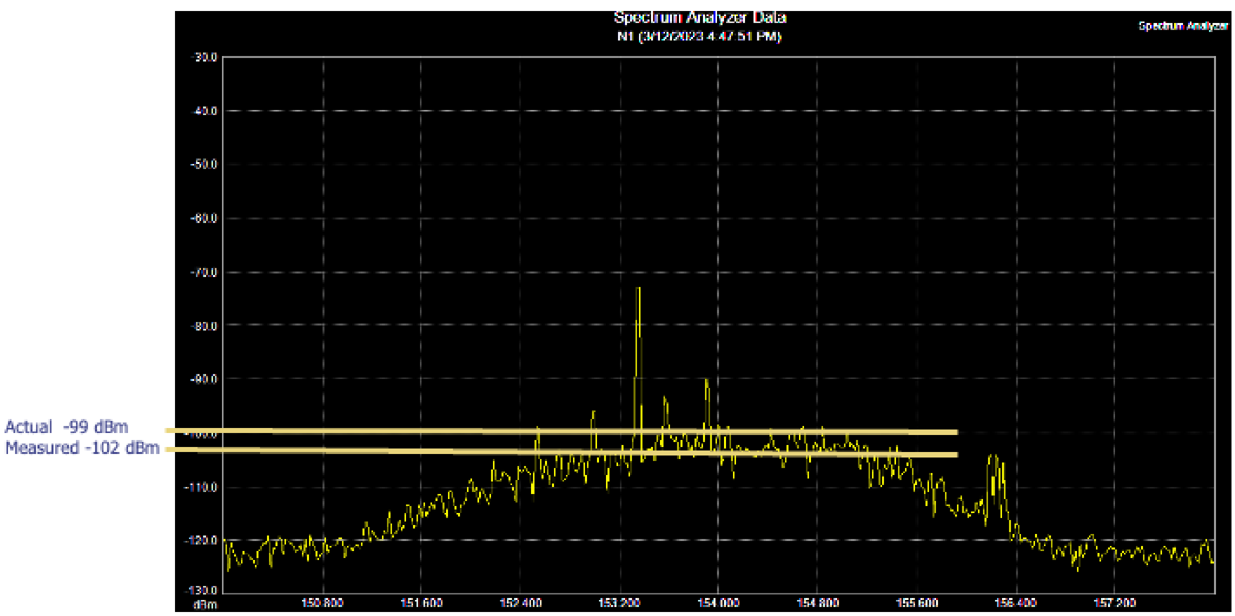

Figure 7: From a measurement taken outside a Costco tire shop, there was very high levels of RF noise (-99 dBm), about 15 dBm above the RF noise floor. The RF noise was likely coming from inside the store. This level of RF noise would make it very difficult for VHF systems to work. (source: J. Blaschka)

Discussion

Following the presentation, the discussion primarily revolved around the methodologies for conducting measurements and pinpointing RF noise sources.

Measurement Practices

Participants emphasized the necessity of establishing best practices or a framework for comparing measurements. One potential approach discussed was the creation of a standardized test setup. Such specifications could be formulated by a group like SpectrumX[15]. Blaschka used a test setup modeled after a land mobile receiver, but an alternative approach could involve utilizing effective receiver sensitivity for measurements.

Identifying RF Noise Sources

The conversation delved into the challenge of identifying RF noise sources. An open question arose regarding whether sources could be deconvolved using measurement techniques or modeling. For instance, when examining data of the aggregate RF noise environment, could contributions from LED lights be distinguished from switching power sources? Such differentiation is desirable because it would allow the most problematic sources to be mitigated.

In some instances, field efforts were undertaken to perform direction finding, aiming to identify specific RF noise sources.[16] However, this task is complicated by several factors. First, some sources are time-based, like lights that only produce RF noise when turned on. This temporal variability makes fieldwork challenging. Second, RF noise pollution can span across several blocks, making it difficult to pinpoint the exact source. It could come from sources such as streetlights or traffic systems, or both. Identifying these systems as sources would necessitate further testing with more precise equipment. There was a general consensus that modeling to distinguish source contributions might be feasible, but it would be a complex undertaking. Small devices exhibit substantial variation, making it challenging to establish broad characterizations. Modeling efforts might yield insights into the RF noise generated by a particular type of switching power supply, but this might not be directly applicable to other brands of switching power supplies.

Finally, some participants pointed out that current receiver technologies might be capable of adapting to accommodate the increasing RF noise levels. Certain issues are concealed by the transition to digital technology, and some systems are incorporating more receivers to cope with the deteriorating RF noise environment. There needs to be a more general understanding of what designers are doing to mitigate the rising noise issue.

Key Findings

The session had key takeaways related to acknowledging and quantifying the problem of rising RF noise pollution. Overall, the goal should be to stop the noise floor from

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[15] https://www.spectrumx.org

[16] Direction finding is a method of locating where a signal is originating from.

going up further. To achieve this requires standardized measurements and a better understanding of the noise sources.

- A consensus is growing that the RF noise floor is a problem, but more understanding of the problem must be developed for people to fully grasp the extent of the issue.
- More work is required on standardizing measurement approaches with a focus on repeatable scientific data as opposed to anecdotal interference cases.
- Locating the exact RF noise source or sources is challenging but it is necessary to develop methods to understand common causes of RF noise. It would not be good regulatory practice to take some action and then find out what was regulated was not the main issue. Therefore, effort needs to go towards understanding RF noise contributions in order for regulation to work well.

IV. Session 3: Research on RF Pollution

Presentation Summary

Andy Clegg, lead spectrum engineer at Google, kicked off this session with a thought-provoking presentation. He demonstrated how the proliferation and diversification of electronic consumer devices within homes have significantly contributed to an observable rise in the RF noise floor within residential environments. To illustrate this point, Clegg conducted RF noise measurements at various locations within his own home.[17]

Clegg's measurements revealed that several commonplace consumer electronic devices emitted substantial levels of RF noise, posing a potential threat to AM and shortwave radio signals. Notable culprits included a dimmer switch, a 2.4 GHz-band remote Wi-Fi switch, a coffee maker, and a television. In one area of his home, the interference was severe enough to disrupt the functioning of Clegg's radio-controlled clock.[18] Strikingly, many of these devices continued to emit significant RF noise even when powered off but still plugged in.

Although Clegg's demonstration was confined to a single domestic setting, it underscored two crucial themes for the session. First, the proliferation of commercial electronic products, often integrated with IoT capabilities, has led to a substantial and potentially problematic increase in RF noise. Second, there is a pressing need for more comprehensive data collection to accurately quantify the RF noise floor and evaluate the extent to which this phenomenon may pose risks of causing harmful interference. As past conferences and roundtable discussions have revealed, establishing even a definition for "harmful interference," let alone an RF noise floor baseline, remains a formidable challenge.

Clegg went on to assert that radio astronomers and other users of similarly sensitive spectrum equipment serve as early detectors of this interference. He aptly remarked, "We're sort of the canaries in the coal mine. We're the first ones to notice all this interference." While Clegg's presentation primarily showcased disruptions in lower-frequency services, he identified several crucial high-frequency and sub-frequency services at risk of disruption from ambient RF noise pollution:

> *"[Radio astronomers are] the canaries in the coal mine. We're the first ones to notice all this interference."*

- Aeronautical and maritime Low Frequency beacons (~200-400 kHz)
- AM broadcast band
- Ham radio on the Medium Frequency and High Frequency bands
- Air traffic management on shortwave
- Shortwave time services (i.e., radio station WWV on 2.5, 5, 10, 15, and 20 MHz)

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[17] *Radio Noise Around the House*, Andy Clegg, https://www.youtube.com/watch?v=ewcemoXLzcU&ab_channel=DetectingTheInvisible

[18] Radio clocks or radio-controlled clocks "are clocks automatically synchronized to a time code transmitted by a radio transmitter connected to a time standard such as an atomic clock." *See* https://en.wikipedia.org/wiki/Radio_clock

- Shortwave broadcast
- CB radio
- Radio astronomy (particularly lower-frequency observations of pulsars and radio bursts)
- Lightning detection systems
- RFID
- Radio controlled (RC) systems (i.e., model planes, etc.)
- Avalanche transceivers
- Navtex marine broadcasts
- Military and utility infrastructureless communications, with ALE

Moreover, Clegg suggested that the expertise within the radio astronomy community and similar communities could be harnessed as invaluable resources in tackling the challenge of defining and addressing RF noise pollution. These communities are well-versed in working with highly sensitive equipment and possess experience in identifying and mitigating unconventional sources of RF noise. While their solutions are often tailored and not easily scalable, Clegg proposed that an initiative to categorize and systematize these efforts could prove fruitful in the initial stages of identifying the sources of background RF noise.

Discussion

Assessing Harmful Interference and Citizen Science

During the session, participants acknowledged that the demonstration had primarily showcased "harmful" interference affecting highly sensitive devices like the previously mentioned radio-controlled clock. However, they stressed that while interference with a hobbyist's household radio-controlled clock might not pose a significant risk, the aggregate increase in the RF noise floor due to a proliferation of emitters could potentially threaten more sensitive measurement equipment used in atmospheric sensing and similar applications. Participants also recognized the potential of grassroots citizen science, as demonstrated in the presentation, as a powerful tool for collecting RF noise measurements.

Data Needs and Informational Deficit

Delving deeper into the nature of interference demonstrated in the household setting, participants explored the data requirements for accurately conceptualizing and quantifying the perceived increase in the aggregate RF noise floor. Although anecdotal, there was strong consensus among participants regarding the need for long-term RF environment measurements across various locations. They highlighted the current scarcity of such data. This discussion underscored the natural convergence between the demand for disaggregated data collection and grassroots citizen science.

Community Air Quality Monitoring Analogy

Drawing an analogy to community air quality monitoring, participants suggested that RF noise pollution research could follow a similar path. Companies like PurpleAir[19] utilize crowdsourced data collection to establish localized air quality models. Similarly, RF noise pollution research could benefit from measurements collected at the local level through grassroots citizen science initiatives.

Long-Term Data Collection and Credibility

Grassroots citizen science could enable more extensive and long-term data collection on RF noise pollution across different localities, a crucial aspect of building a comprehensive understanding of the RF environment. Participants emphasized the importance of data collected over time to support the anecdotal evidence suggesting an increase in the baseline RF noise floor. Whether collected at a single location over time or through crowdsourced research solutions discussed during the roundtable, this data could provide greater insight and, importantly, enhance the credibility of the hypothesis that the RF noise floor has risen in parallel with the growth of intentional and unintentional emitters. While participants generally agreed on the assertion that the noise floor has increased, they emphasized the need for quantifying this change comprehensively.

Key Findings

Key findings from the session highlight the issues with consumer electronics and present some possible starting points to define and quantify noise.

- The sheer volume of RF noise and the number of potential environments means any attempt to define a 'baseline' RF noise floor will require innovative and alternative approaches to gathering information.
- Potential citizen science solutions and leveraging the expertise of the radio astronomy community should be explored as options for solving the information deficit.
- Ambient RF noise can be found emitting from a wide variety of household consumer electronics; switched power supplies in consumer electronics are one potential culprit and worth further study.
- The wide array of consumer electronics emitting ambient RF noise may also warrant a second look.

[19] PurpleAir is a company that sells particle pollution sensors directly to consumers and produces air quality index maps based on the information gathered from consumer sensor readings. For more information visit https://www2.purpleair.com/.

V. Session 4: Enforcement

Presentation Summary

Lynn Claudy, Senior Vice President at the National Association of Broadcasters, commenced the discussion with a retrospective view of interference concerns and their enforcement. Claudy emphasized that interference cannot be discussed in isolation, likening it to politics, with a key principle: all interference is essentially local. Claudy asserted that the FCC, in recent times, has consciously strived to enhance RF spectrum user density. However, this pursuit naturally engenders tension when it comes to interference concerns. He commended the FCC's recent policy statement as a significant step toward addressing the more intensive use of the limited resource that is the RF spectrum.[20]

This policy statement can be traced back to the efforts of the FCC Technological Advisory Council (TAC) on receiver standards in 2015. Claudy expressed support for notifying spectrum users that intensifying spectrum use will necessitate the design of systems, including transmitters and receivers, capable of functioning effectively in a congested spectrum environment.[21] By characterizing this holistic emphasis on system performance as a positive development in spectrum policy, Claudy circled back to the enforcement aspect by acknowledging its limitations in dealing with willful violators who operate outside their allocated spectrum or FCC rules.

He illustrated this point with an example from the mid-2000s, involving enforcement action against manufacturers of low-power FM modulators used for interfacing media devices such as mp3 players and satellite radio to car audio systems. Initially adhering to Part 15 rules on transmission power, these unlicensed devices were designed to plug into a vehicle's 12V auxiliary power outlet and allowed users to tune in their radio to the FM transmission from the device. However, as their popularity grew, competitive pressure led manufacturers to increase the transmitting power of these devices, resulting in interference with licensed broadcast stations or other unlicensed FM transmitters when in close proximity to other vehicles.

> *"…you need to stay in your lane, if it's possible for you to do that. Problem, of course, is that even if you stay in your lane, there are others who want to swerve into your lane…"*

The FCC took effective enforcement action by auditing many of these devices, revealing that most operated at power levels significantly exceeding the limits specified in Part 15 rules. Subsequent Notices of Apparent Liability were sufficient to resolve the issue and bring the manufacturers of these FM transmitters back into compliance.

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[20] *Principles for Promoting Efficient Use of Spectrum and Opportunities for New Services*, Policy Statement, FCC-23-27 (rel. Apr. 21, 2023), https://www.fcc.gov/document/fcc-states-spectrum-management-principles-transmitters-receivers-0

[21] *Interference Limits Policy and Harm Claim Thresholds: An Introduction,* FCC Technological Advisory Council, (March 5, 2014)

Likewise, Claudy cited FCC enforcement action against pirate radio[22] as another successful example of the FCC, with help from Congress, stepping in to rectify the behavior of bad actors. Claudy supplied evidence, shown in Figure 8, that pirate radio broadcasters were particularly rampant in the 2010s.

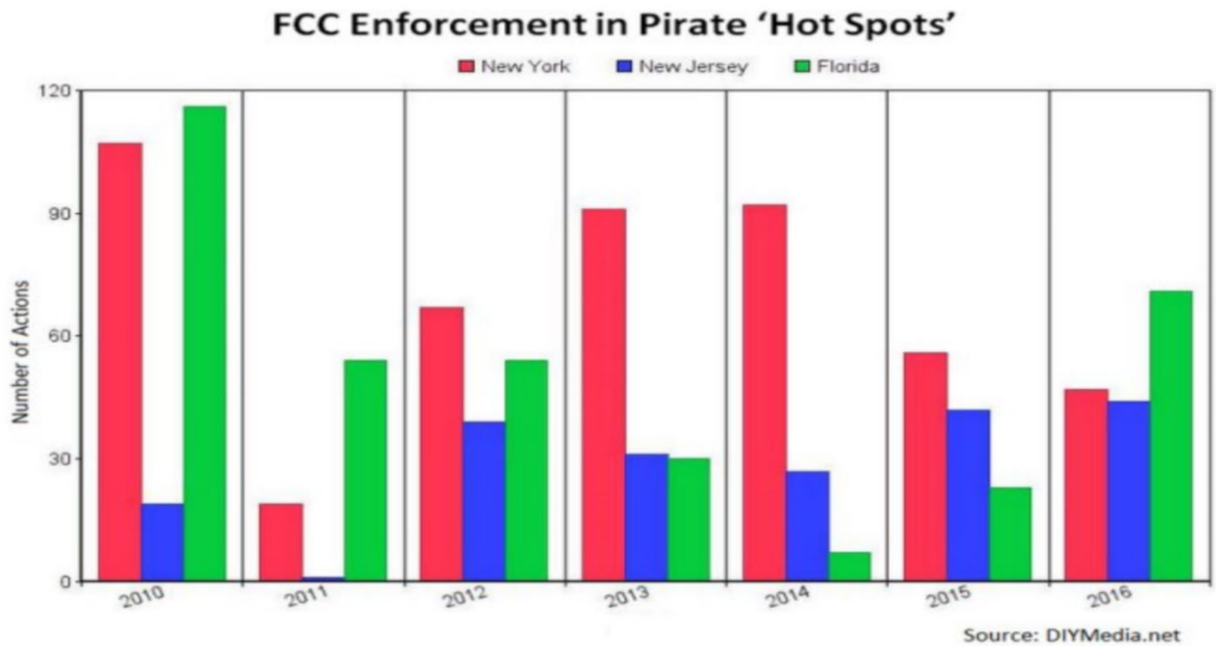

Figure 8: Data shows the drop in the number of pirate radio broadcasters since 2010.

However, at the time the FCC lacked sufficient authority to properly go after landlords of properties hosting rogue transmitters or levy significant financial penalties on pirate broadcasters. This changed in 2020 with the passage of the Preventing Illegal Radio Abuse Through Enforcement Act ("PIRATE Act").[23] Following the passage of the PIRATE Act, enforcement actions against pirate radio broadcasters plummeted. Claudy argued that this demonstrated how directed action and strong enforcement capacity could be an effective deterrent against certain types of bad actors who prompt enforcement actions.

Claudy cautioned however that while these examples demonstrated successful enforcement actions, changes in FCC resources and the changing landscape of interference resolution may complicate the FCC's role as a modern enforcement agency. He posed a critical question about the FCC's readiness to effectively tackle bad actors causing interference in an increasingly crowded and diverse interference landscape. In contrast to the FCC's effective response to rogue FM transmitter manufacturers and pirate radio broadcasters, Claudy highlighted the persistence of jamming devices, which, despite being highly illegal, remain available for purchase online. He also underscored the substantial decrease in tangible enforcement resources at the disposal of the FCC (see Figure 9).

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[22] "Pirate radio" refers to radio broadcasters operating without necessary licensure from relevant governmental agencies.
[23] *Codified at* 47 U.S.C § 511.

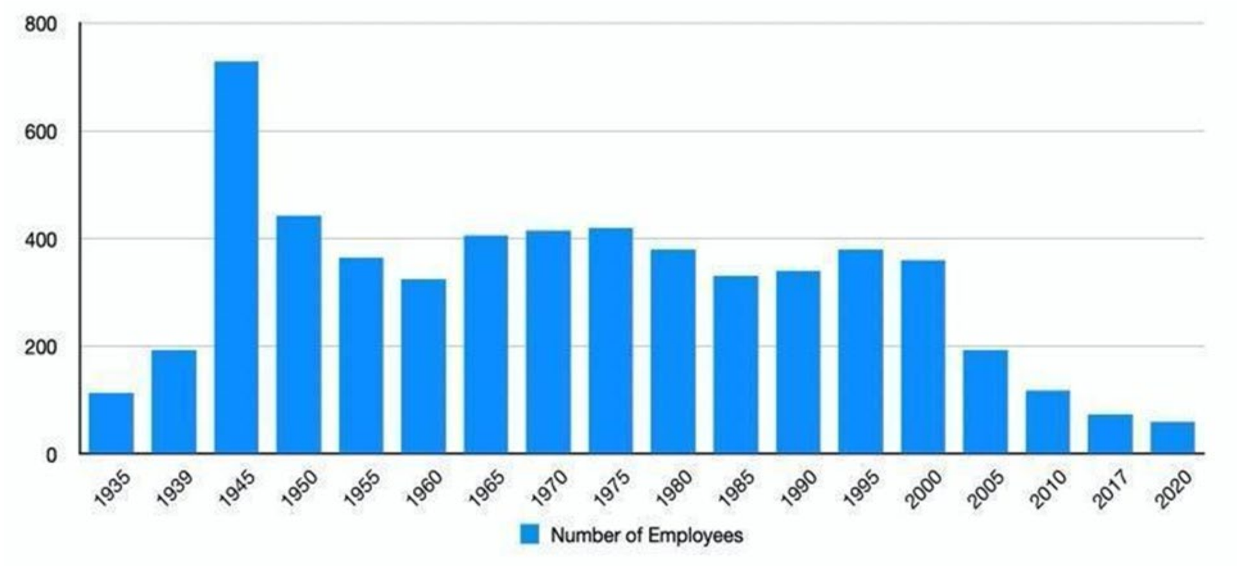

Figure 9: Data shows the decrease in the number of FCC employees. (source: https://www.fcc.gov/reports-research/reports/annual-reports-congress?page=0)

This diminishing physical presence for enforcement, coupled with the increasingly diverse interference landscape, was encapsulated by one participant who remarked.

"Back in the day, it was a big tower, easy to find, and you shut it down. Now you have 64 devices in your house; are you going to let me into your house to look at all 64 and see what's causing the problem?"

Claudy concisely summarized the enforcement challenge facing the modern FCC within the evolving RF spectrum environment. He emphasized the necessity for government and industry collaboration to discover effective enforcement solutions that don't rely solely on old school approaches like trucks with antennas and other physical FCC enforcement resources. He posed several key questions to guide the session before opening the floor for group discussion: (1) How should the responsibility for enforcement be allocated between industry and the potentially under-equipped and overburdened FCC enforcement capacity? (2) How can we harness new technologies, such as artificial intelligence, to enhance enforcement outcomes? (3) What other opportunities may exist to bolster enforcement capacity against bad actors?

Discussion

Lack of Enforcement Capacity

The discussion during this session began with a consensus among roundtable presenters regarding the long-standing issue of the FCC's inadequate enforcement capacity, which showed no signs of improvement. While participants recognized the past success of an enforcement action against FM transmitters that exceeded power limits, doubts emerged regarding whether the Part 15 equipment testing process effectively screened devices before they entered the market. Many agreed that manufacturers of Part 15 equipment had the opportunity and means to be deceptive during testing. A participant raised the concern that bad actors might submit a decoy device for testing, one that complies with standards but differs from the actual production device—an idea met with general agreement among participants.

Another significant shortcoming of the FCC's enforcement capacity discussed at length was the often impractical timetable for enforcement actions. The process initiated upon receiving a complaint, necessitating testing to confirm the alleged interferer and assess the extent of their violations. This timetable was viewed as inadequate, resembling a never-ending game of "whack-a-mole." Once one offender was identified, enforcement actions were taken, causing them to cease their interference activities. However, a new offender would soon emerge. This rapid cycle hinders the efficient and effective resolution of interference issues.

Industry-Driven vs. FCC-Driven Enforcement

The participants also reached a consensus regarding the cooperative nature of modern enforcement, with the FCC and industry playing vital roles. Questions arose concerning how the marketplace itself addressed bad actors and promoted cooperation among spectrum users in the absence of a robust central enforcement mechanism from the FCC. Participants agreed that voluntary cooperation among market participants often depended on the unique relationships among spectrum users.

The roundtable proposed two distinct perspectives on enforcement disputes: (1) those with market mechanisms in place to resolve disputes and (2) those without such mechanisms. For example, Commercial Mobile Radio Services (CMRS) providers exemplified the former category. CMRS providers have economic incentives to coordinate their RF spectrum use and minimize interference with each other because they are often directly linked. Two CMRS providers aimed for the same outcome—stability and predictability in their interference environment. When one exceeded its license terms, it could incur costs for another, creating a reciprocal relationship that encouraged cooperation.

In contrast, Part 15 device manufacturers have no economic relationship with parties they might interfere with. No substantial market mechanism existed to correct the behavior of bad actors. For instance, broadcasters potentially interfered with by FM modulators, governed by Part 15 regulations, had no economic ties to the device manufacturers. The manufacturers faced no reciprocal harm if broadcasters failed to adhere to their license terms, offering insufficient financial incentives for modifying their behavior. Historical conflicts between "untethered" services like these often necessitated FCC intervention in an enforcement capacity to rectify the behavior.

Use of New Technologies

Finally, participants delved into the potential of technology to enhance enforcement outcomes. The spotlight fell on artificial intelligence (AI) as a game-changer in the realm of detecting bad actor behavior, streamlining enforcement actions, and fostering improved spectrum coordination. Considering the challenges associated with initiating enforcement actions promptly, participants raised thought-provoking questions about the role of machine learning and AI in creating a more agile and efficient enforcement regime.

Key Findings

One of the key takeaways from the session was a 'bucket' system to categorize enforcement contexts. A participant suggested that there were proactive, reactive, and a "no-man's land."

Proactive Enforcement Solutions

- Issues that can be addressed on the front end, e.g., Part 15 standards, spectrum licensing rules and regulations.
- Front end categorization and definition of the RF noise floor is one potential proactive approach.
- Decisions made at the testing and production phase could also serve to reduce the individual contributions of passive and unintentional radiators such as consumer electronics to RF noise pollution.
- Specifically, participants identified what equipment design modifications might be considered for switched power supplies.

Reactive Enforcement Solutions

- Reactive enforcement actions arise in direct response to the behavior of bad actors after the fact. Examples of this enforcement include previously discussed FM adapters and pirate radio station broadcasts.
- These are often necessary when criminality or noncompliance is present; front-end testing and standardization cannot directly address individuals who deliberately circumvent or violate rules or regulations.

No-Man's Land and the RF Noise Floor

The final bucket was coined by one participant as the "No-Man's Land" - neither neatly fitting into reactive or proactive solutions.

- These types of enforcement are not a product of blatant misbehavior, like reactive solutions typically are.
- Some issues are not sufficiently solved by proactive solutions, as many devices contributing the the rise in the RF noise floor are fully compliant and operating within their established parameters.
- "No-Man's Land" refers to the fact that no one device or actor is responsible for an increased RF noise floor from aggregate emissions, and that the problem cannot be neatly solved by existing proactive or reactive solutions.
- Reactive solutions pose unique challenges: incumbent users are unlikely to be receptive to modifying behavior that was previously condoned, and transaction costs for modifying devices on the market already or recalling them are likely impractical.

VI. Session 5: Looking Ahead

Presentation Summary

> *"[H]ow much does a one dB rise in the noise floor cost?"*

The session commenced with an icebreaker titled "Exploring Long-Term Prospects for Sweeping Changes in the Manmade Noise Pollution Environment," presented by Dale Hatfield. The objective of this icebreaker was to offer a broader perspective on shifts in the man-made noise environment. The increasing adoption of novel equipment is leading to the proliferation of ambient RF noise. Examples of this trend include electric vehicles, solar power collection, wind farm power transmission, and switched power devices. Hatfield underscored the necessity of recognizing the trade-off in pollution, highlighting that traditional power sources generated minimal noise, while newer environmentally friendly technologies often incorporate high-power, switched equipment that emits RF noise.

Furthermore, Hatfield emphasized the rapidly evolving landscape. In order to formulate effective policies, stakeholders must plan for the evolving environment, rather than focusing solely on its current state. Achieving this goal necessitates establishing clear connections between noise sources and consequences if those sources are left unregulated.

Discussion

Economic Complexities and Transparency Models

Economic arguments and considerations featured prominently in this session. Participants underscored the economic dynamics and the diverse array of stakeholders that complicate the problem. Among these stakeholders, mention was made of low-cost device manufacturers, whose designs may not factor in RF noise; government agencies, such as the Department of Transportation, concerned with AM radios in vehicles and noise stemming from automotive components; and the power industry, building extensive networks of high power transmission lines and the increase of electric vehicle charging and battery systems. The challenge lies in the fact that these industries might not fully grasp or internalize the costs associated with increased RF noise, creating a hurdle for arriving at a natural economic solution.

> *"... noisy switching power supplies, solar panels, whatever it is, automobiles, they're basically shifting what should be their cost over to the communications industry, which incurs higher costs."*

To put a price tag on the issue, participants discussed the importance of estimating the costs associated with a noise floor increase. For instance, they pondered how many additional sites a carrier might need to deploy if the noise floor rises 1 dB and what the cost of that infrastructure expansion would be. Quantifying the economic impact could serve as a wake-up call, shedding light on how much a noisy device in one industry shifts costs onto the communication industry.

Transparency-Driven Noise Mitigation Model

Another model that surfaced involved enhancing transparency regarding noise. Drawing inspiration from the amateur radio community, which identifies noisy equipment and exerts pressure for quieter components through purchasing power, participants proposed a similar model of noise transparency that could foster competition in producing low-noise devices. However, they acknowledged a roadblock here: public awareness. Currently, the public lacks awareness of the issue because, with the transition from analog to digital technology, people no longer visibly perceive RF noise. Instead, they merely experience a signal loss, which could be attributed to various causes.

Participants also considered the shift in policy favoring wireless over wired solutions, which could contribute to elevated noise levels. They proposed the idea of introducing regulations to enforce engineering design practices for low-noise devices as a potential remedy to the situation.

Key Findings

The key findings for this session include:

- Other industries are shifting costs to the communications industry, so there needs to be a better understanding of the economic impact of an increased RF noise floor.
- As this is happening, it is critical to look at what can be mitigated and what cannot and start making proactive policy. Part of this may include identifying what can be protected and what services or uses may need to preemptively change frequencies or consider design modifications.
- From a regulatory perspective each state is taking a different approach to electrification which could provide a variety of case studies to compare RF noise in different geographic areas.
- Similar to earlier sessions, this session emphasized a need to quantify the issue and pursue economic or regulatory measures for mitigation.

VII. Conclusion

In discussing the RF noise pollution issue, the 2023 Roundtable revisited many of the issues that were brought up by the 2013 Conference. Much like the 2013 Conference, participants found that "strong evidence suggests that the RF noise floor is rising in… bands critical to many wireless systems…" Our Roundtable participants suggested that the RF noise floor has only continued to rise, and that the footprint of a higher RF noise floor is becoming unmistakable.[24] Even in 2013, participants recognized a "pressing need for more systematic, transparent, and scientifically-based measurements…"[25] The fact these statements are almost precisely echoed ten years later indicates that the problem remains, and little action has been taken to address the issue.

From the outset, this roundtable aimed to determine whether the Silicon Flatirons Center should host a conference to address the threat posed by the rising RF noise floor. In each session, participants raised the need to establish standards for analyzing and quantifying the rising RF noise floor as a vital first step. This need should not come as a surprise - our 2013 Conference report concluded on a similar note stating, "panelists recognized a pressing need for more systematic, transparent, and scientifically based measurements in order to conduct a cost-benefit analysis that would support the development of new or revised standards for radio noise emissions." Clearly, this warning was not heeded, and a new conference is necessary to address the rising RF noise floor.

Silicon Flatirons should hold a conference bringing industry, policymakers, and academics together to:

1. Determine why standard methodologies have not been adopted in the past ten years; and
2. Lay out a roadmap for cooperating to establish such methodologies.

In preparation for future discussions, we propose the following topics for more targeted research and development:

1. Researchers could create and propose some detailed standards for measurements. These proposed standards could be reviewed by industry stakeholders.
2. Additional case studies could be conducted on measuring RF noise in a specific geographic location. Researchers could conduct field work on identifying contributions from specific emitters in order to provide a better understanding of how different sources affect the noise environment.
3. Modeling work could be taken on to assess the feasibility of deconvolving RF noise sources from an aggregate RF noise profile. Both through field studies and modeling, being able to identify the "worst-offenders" would provide a stronger basis for introducing new regulations.
4. Studies could be conducted to measure the amount of noise produced by different manufacturers of the same type of device. For example, do all street light designs produce comparable levels of RF noise? Understanding where

[24] 2013 Conference Report at 17.
[25] *Id.* at 17-18.

generalizations can be made would help with advising consumers as well as setting policy.

VIII. Participants

Beau Backus – John Hopkins University Applied Physics Laboratory

Ken Baker – University of Colorado

Joe Blaschka – CEJA Engineering

John Chapin – National Science Foundation

Lynn Claudy – National Association of Broadcasters

Andy Clegg – Google

Jeff Correia – MITRE

Arthur DeLeon – Department of the Navy CIO

Tom Dombrowsky – DLA Piper

Ed Drocella – National Telecommunications and Information Administration / Office of Spectrum Management

Tim Godfrey – Electric Power Research Institute

Keith Gremban – Silicon Flatirons

Dale Hatfield – Silicon Flatirons

Ira Keltz - Federal Communications Commission Office of Engineering and Technology

Julius Knapp – Federal Communications Commission (retired)

Todd Martin – Shared Spectrum

Christina McCann – Department of the Navy CIO

Scott Palo – University of Colorado

Bob Pavlak - Federal Communications Commission

David Redl – Salt Point Strategies

David Siddall – American Radio Relay League, The National Association for Amateur Radio

Albert Spencer – National Oceanic and Atmospheric Administration / National Weather Service

Peter Tenhula – Silicon Flatirons

Darcy Walsh – Freedom Technologies

Tomasz Wojtaszek – National Oceanic and Atmospheric Administration / National Weather Service

IX. Acronyms

ALE Automatic Link Establishment

AM Amplitude Modulation

CB Citizen's Band

CBRS Citizens Broadband Radio Service

EPA Environmental Protection Agency

EV Electric Vehicle

FCC Federal Communications Commission

GHz gigahertz, or 1,000,000,000 cycles per second

IoT Internet of Things

ISM Industrial, Scientific, and Medical

kHz kilohertz, or 1,000 cycles per second

LED Light-Emitting Diode

MHz megahertz, or 1,000,000 cycles per second

NSA National Security Agency

OET Office of Engineering Technology (FCC)

RF Radio Frequency

RFID Radio Frequency Identification

RMS Root Mean Square

TAC Technological Advisory Council

VHF Very High Frequency

X. About Silicon Flatirons Center

Mission

Silicon Flatirons' mission is to elevate the debate surrounding technology policy issues; support and enable entrepreneurship in the technology community; and inspire, prepare, and place students in these important areas. Learn more at siliconflatirons.org/about-us/.

Spectrum Policy Initiative

Spectrum policy dictates how, where, and when wireless services can be delivered to devices—and it has deep ramifications for the economy, scientific development, national security, personal enjoyment, and more. Since 2005, Silicon Flatirons has explored the intersection of policy and engineering in the heavily regulated and rapidly changing wireless services industry.

Silicon Flatirons convenes stakeholders and provides law and engineering students with a foundational understanding of spectrum policy. The Spectrum Policy Initiative engages a wide range of wireless industry professionals, radio engineering professionals, and spectrum policymakers from Colorado, Washington, D.C., and across the country.

Learn more about the Spectrum Policy Initiative and other Silicon Flatirons Initiatives at siliconflatirons.org/initiatives/.

Our Team

For more information about center leadership, faculty, staff, fellows, and advisory board, visit siliconflatirons.org/about-us/our-team/.

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Publications

We promote thought leadership and intellectually honest discourse not only in our events, but in publications from our team, our roundtables, and scholars presenting at our conferences. See more at siliconflatirons.org/publications/.