**Radio Spectrum Pollution: Facing the Challenge of a Threatened Resource**
A report on a Silicon Flatirons Conference, held 14 November 2013

*By: John Cook, Megan Coontz McAllister, and Laura Littman*[*]
31 January 2014

## Executive Summary

On November 14, 2013, the Silicon Flatirons Center hosted the conference "Radio Spectrum Pollution: Facing the Challenge of a Threatened Resource" at the University of Colorado Law School.

Intensive use of radio frequencies by wireless systems is crucial to our economic and social wellbeing and to national defense and homeland security. Successful operation is essential for a wide variety of wireless applications, ranging from simple keyless entry systems and garage door openers, to broadcasting networks, Wi-Fi and cellular networks, complex navigation systems like GPS and radar, and mobile radio systems relied upon by first responders. By analogy to other important economic inputs like coal, water, and know-how, one can think of radio frequencies—also known as spectrum—as a resource.

The proliferation of wireless devices along with the increasing amount of frequency capacity consumed by each device (e.g. tablet computers used to upload or download video programming) puts intense pressure on the resource—a topic addressed at previous Silicon Flatirons events.[1]

The good news is that, unlike other important natural resources such as oil, coal, or natural gas, the spectrum resource is not destroyed by use—it is infinitely renewable. However, like air and water, the spectrum resource can be polluted. In spectrum, pollution takes the form of interference from other radio sources. Since the performance of a radio link depends upon the strength of the desired signal relative to the strength of undesired interfering signals, increased background radio noise can reduce the total carrying capacity of the resource. When severe, the noise pollution manifests itself, for example, in the form of hissing or popping on radio channels, picture loss on television or other video feeds, interrupted wireless voice conversations, slow or

---

[*] *John Cook IV, 2015 J.D. Candidate at the University of Colorado Law School,*
*Megan Coontz, 2015 J.D. Candidate at the University of Colorado Law School,*
*Laura Littman, Research Fellow, Silicon Flatirons, JD University of Colorado Law School 2013.*

[1] *See The Digital Broadband Migration: The Future of Internet-Enabled Innovation*, Silicon Flatirons Center Conference (February 10-11, 2013), http://www.siliconflatirons.com/events.php?id=1122; *Looking Back to Look Forward: The Next ten years of Spectrum Policy*, Silicon Flatirons Center Conference (November 13, 2012), http://www.siliconflatirons.com/events.php?id=1203; *Receivers, Interference and Regulatory Options*, Silicon Flatirons Center Roundtable (November 13, 2012), http://www.siliconflatirons.com/events.php?id=1270; *Efficient Interference Management: Regulation, Receivers, and Rights Enforcement,* Silicon Flatirons Center Roundtable (October 18, 2011), http://www.siliconflatirons.com/events.php?id=1021; *The Unfinished Radio Revolution: New Approaches to Handling Wireless Interference*, Silicon Flatirons Center Conference (November 12, 2010), http://www.siliconflatirons.com/events.php?id=862; *Wireless Broadband: Markets, Models and Spectrum*, Silicon Flatirons Center Conference (September 8, 2010), http://www.siliconflatirons.com/events.php?id=831; *The Future of Spectrum Management: Private Property Rights or Open Standards?*, Silicon Flatirons Center Conference (March 5, 2002), http://www.siliconflatirons.com/events.php?id=69.

intermittent internet connections, and—in extreme cases—degradation of communication and navigation systems that are vital to national security and homeland defense.

This conference focused on radio frequency noise rather than interference in general, of which noise is a subset. In general usage, “noise” means energy (electromagnetic or sonic) that some particular person finds unwelcome given their activities. However, the conference and this report use the following more circumscribed definition: noise is radio frequency interference that does not come from an identifiable, intentional radiator.

Three broad sub-categories of noise are:

(1) Natural (not man-made) environmental noise, e.g. from lightning and atmospheric processes (most important at lower frequencies).
(2) Interference from unintentional radiators, e.g. switching power supplies in fluorescent and LED light fixtures (often called “man-made” noise to distinguish it from the first category).
(3) Aggregate out-of-band interference from a “sea” of intentional radiators, e.g. out-of-band emissions (OOBE) from hundreds or thousands of nearby transmitters leaking into noise-limited services like satellite or radar receivers.

While there are regulations at the international and national level aimed at controlling man-made sources of interference, they are becoming more important because of the increasing number of devices involved, the close proximity within which they must operate, and the increasing importance of wireless services.

Since the level of aggregate radio noise from both natural and human sources tends to decrease as frequencies become higher, the intense interest in noise levels back in the days of short- and medium-wave radio has declined with the shift of critical wireless systems to higher frequencies. However, evidence is emerging that the radio noise floor is rising in higher-frequency bands that are especially important to both commercial and public safety applications.

This conference brought together academics, policymakers, spectrum users, and advocates to examine the extent of, and trends in, radio noise pollution and to explore how the associated policies and regulations may need adjustment to reflect changes in radio noise levels.

Prior to the conference, Robert Matheson presented a tutorial on noise for people who wanted more background information about the panel content.[2] The conference opened with a keynote by Julius Knapp,[3] Chief of the FCC’s Office of Engineering and Technology, followed by four panels:

Panel 1: Measurements—Discussing how radio noise is characterized and measured.

[2] Slides from Robert Matheson’s tutorial are available at http://www.silicon-flatirons.org/events.php?id=1365 in PDF and PowerPoint format (the PowerPoint format includes animation).
[3] Slides from Julius Knapp’s presentation are available at http://www.silicon-flatirons.org/documents/conferences/2013-11-14%20Spectrum/Silicon%20Flatirons%20Keynote%2011-13-14.pdf.

Panel 2: Services and Scenarios—Identifying what types and levels of noise pollution service providers and other users of the resource are actually observing in the field and the trends associated with those observations.

Panel 3: Lessons from Environmental Pollution—Comparing and contrasting approaches used to control other forms of pollution (e.g., water and air) with those used in protecting the radio spectrum environment.

Panel 4: Enforcement & Policy Initiatives—Discussing what tools are available in terms of both processes and advanced systems for enforcement and where priorities should lie.

To conclude, this report answers the "why care" question about noise pollution—why are noise pollution and the increasing noise floor important topics that deserve attention from the industry and regulators?

A video of the conference is available at http://www.silicon-flatirons.org/events.php?id=1365.

Additionally, prior to the conference on noise, several of the conference panelists participated in a roundtable discussion about spectrum enforcement, hosted by Silicon Flatirons. A report from the roundtable is available at http://www.siliconflatirons.com/initiatives.php?id=SpectrumEnforce.

## Opening Keynote: Julius Knapp

Julius Knapp, Chief of the FCC's Office of Engineering and Technology, began the discussion by outlining relevant FCC Rule provisions for controlling radio noise and presented observations and topics for discussion.[4] Knapp outlined relevant FCC Rule provisions in three regulated categories: unlicensed devices, industrial scientific medical equipment, and licensed radio services. He noted that various organizations are working to address radio noise issues, including the International Telecommunications Union (ITU), the International Union of Radio Science (URSI), the American Radio Relay League (AARL), voluntary standard-setting bodies, and the National Academies Committee on Radio Frequencies (CORF). Knapp concluded his presentation by offering his observations and suggested key takeaways about radio noise regulation, as discussed below.

### (1) *Unlicensed Devices, Industrial Scientific Medical Equipment, and Licensed Radio Services*

*Regulation of unlicensed devices*: Unlicensed devices generally operate on unused spectrum "overlay" or in industrial, scientific, and medical (ISM) radio "junk bands." They are restricted from some frequency bands, including those for public safety and low-signal band use. To address interference issues, the industry developed voluntary protocol standards within the framework of FCC Rules. Knapp noted that in the case of unlicensed devices, avoiding harmful interference is a "good engineering practice" standard but is not a technical requirement. Knapp identified the following unlicensed devices: radio frequency (RF) devices, incidental radiators, unintentional radiators, digital devices, and intentional radiators.

[4] Julius Knapp, *FCC Provisions for Controlling Radio Noise*, Slides, Silicon Flatirons Conference on Radio Spectrum Pollution: Facing the Challenge of a Threatened Resource (November 13, 2013), available at http://www.silicon-flatirons.org/documents/conferences/2013-11-14%20Spectrum/Silicon%20Flatirons%20Keynote%2011-13-14.pdf.

*RF devices:* Part 15 regulates RF Devices and specifies Electromagnetic Compatibility (EMC) requirements for most electronic equipment. Part 15 allows lower-power radio transmitters to operate without the need to obtain a license under the following two operating conditions—the transmission cannot cause harmful interference and interference that is received must be accepted.

*Incidental radiators*: Incidental radiators are defined as any device that unintentionally produces RF energy as a by-product of its operation, such as electric motors and antennas. As a condition of operation under FCC Rules, incidental radiators must not cause harmful interference.

*Unintentional radiators*: An unintentional radiator is a device that intentionally generates radio frequency within itself and connected equipment but that unintentionally emits RF energy by radiation or induction. Examples of unintentional radiators include DVD players, tablets, and MP3 players. There are two classes of unintentional radiators, which are based on separation distance—"general devices" are limited by a 3-meter separation and "commercial devices" require a greater separation.

*Digital devices*: A digital device is defined by FCC Rules as a device or system that generates and uses timing signals or pulses at a rate in excess of 9,000 pulses per second and that uses digital techniques. Digital devices are divided into the following two classes: "Class A" is marketed for a commercial and industrial environment and "Class B" is marketed for a residential environment. Knapp emphasized that appliances, transportation vehicles, test equipment, and industrial control systems are exempted from this classification.

*Intentional radiators*: Intentional radiators are devices that intentionally generate and emit radio frequency energy by radiation or induction, such as Wi-Fi or Bluetooth. According to Knapp, the FCC Rules minimize the likelihood of interference by unlicensed devices by identifying permissible frequencies, limiting power to very low levels, specifying out-of-band and spurious emissions limits, and requiring equipment authorization.

*Regulation of scientific medical equipment and licensed radio services*: ISM is equipment that uses and generates RF to perform non-telecommunications work. Examples include dielectric heaters, wood-gluing machines, microwave ovens, and more recently, wireless power transfer and RF lighting.

*Regulation of licensed radio services*: Licensed radio services utilize licensed transmitters that emit energy both in- and out-of-band. Knapp explained that licensed transmitters have more stringent requirements in many cases, and he noted that the industry has set additional standards to prevent interference. Knapp argued that applying limits to licensed radio services has become more complex as modes of operation increase and as more devices contain multiple transmitters.

**(2) *Observations and takeaways***

*The absence of scientifically derived data assessing radio noise activity impedes a cost-benefit analysis that is necessary for the development of viable standards to address interference*: Knapp asserted that radio spectrum is a critical resource that should be protected; however, he noted that there is not enough scientifically derived data measuring noise floor activities to viably assess noise issues. He explained that most existing radio noise evidence is anecdotal, adding that measuring noise is a difficult task. Thus, he said that methods of noise measurement should be a topic of future discussions. Because there are numerous sources of noise and little data on the most significant contributors, Knapp said it is difficult to quantify the costs of reducing noise levels. He argued that a benefit assessment of noise reduction is similarly difficult; because one party's desired signal might be noise to another, it is not clear what constitutes a reasonable target for noise interference. Finally, he recognized that because it is not clear what infrastructural costs would be reduced or if service quality and reliability would be improved, many obstacles stand in the way of developing viable standards.

*A more specific definition for "harmful interference" could be the "Holy Grail" for addressing interference problems*: Knapp noted that radio noise is not a new phenomenon and argued that while it would be ideal to have zero man-made radio noise, this is not a practical solution. Knapp said that the true challenge presented is how to develop viable standards and strike the right balance between costs and impact, which, he said, requires a specific definition for harmful interference.

*There are fundamental differences between environmental emissions standards and radio noise emissions issues*: Knapp questioned whether the environmental model translates well to radio noise emissions. Knapp argued that unlike environmental emissions, radio emissions vary greatly between different modes of operation and each individual device has little impact. Knapp concluded by observing that unlike environmental emissions, incentives to reduce radio emissions are not clear.

## Panel 1: Measurements

***Panelists****: Dale Hatfield, Co-Director, Spectrum Policy Initiative, Senior Fellow, Silicon Flatirons Center, and Adjunct Professor, University of Colorado; Robert Matheson, Retired, U.S. Department of Commerce NTIA/ITS; Mark McHenry, Founder, Shared Spectrum Company; Frank Sanders, Chief, Telecommunications Theory Division NTIA/ITS, and Jeff Wepman, Engineer, Spectrum and Propagation Measurement Division, NTIA/ITS.* ***Moderator****: Pierre de Vries, Co-Director, Spectrum Policy Initiative, and Senior Adjunct Fellow, Silicon Flatirons Center.*

The first panel discussed radio noise characterization and measurement. The discussion covered the following topics: (1) types of measurement, (2) challenges in taking measurements, (3) interpreting measurements, and (4) policy implications of noise measurements.

### (1) *Types of measurement*

*Taxonomy of noise and interference*: First, the panelists proposed taxonomies of noise and interference and debated whether there is a difference between the two categorizations. Wepman offered a taxonomy that distinguishes noise and interference based on source, specifying that noise comes from unintentional, man-made sources (e.g. computers and lights) and natural sources of radiation. However, Wepman suggested that maybe the distinction is not really important—when making measurements, things can be simplified, he said. Sanders added that there is no standard methodology for measuring noise. McHenry concluded that it is a highly complex problem and there is no easy way to delineate between noise and interference.

*Measurements used today*: Matheson identified root mean square (RMS) as the one universal measurement used for radio noise. RMS can be measured accurately and is easily adjusted for bandwidth. However, he thinks that RMS data could be augmented to include statistical information like APDs or peak readings. Importantly, he noted that higher peak readings can be caused by wider measurement bandwidths and should not be confused with increased noise power (i.e., higher RMS).

**(2) *Challenges in taking measurements***

*Taking useful measurements*: Sanders observed that the process of measurement depends on what a researcher is seeking; researchers can minimize or accentuate the impact of radiation based on the methodology and technique employed. Thus, he argued that noise should be measured with a variety of detectors and bandwidths. The key, he said, is to report the measurement in a way that is understandable and comprehensive. Further, he suggested that to make better measurements, there must be investment in people and hardware. Finally, he said that a thorough understanding of common pitfalls of measurements is important in order to support improvement.

*Basic challenges of noise and interference measurements*: Wepman suggested that to take a formal measurement, one must ensure that there are no unwanted signals in the band and then determine whether the measured signals are above or below the noise floor. However, it is very difficult to ensure that there are no unwanted signals in the band because of out-of-band interference. Sanders added that reporting techniques should consist of taking broad readings and using a comprehensive report to draw tailored conclusions. Wepman observed that a challenge is ensuring that the spectrum is free from intentional radiators—because spectrum use varies day-to-day, it would be ideal to sense all radiators before measuring.

*Measurement changes based on frequency*: McHenry explained that looking across a wide range of frequencies, while the probability of finding radiation is about the same, in each frequency, the frequency band determines how far the radiation will travel.[5] Noise readings are highly dependent on what frequency range or band the reading is in, said Wepman. Frequency bands below 20 MHz can include high levels of atmospheric noise. In very high frequency (VHF) bands, man-made noise becomes more dominant. Issues with noise decrease as frequency increases. Both Sanders and Wepman noted that most studies are below 1 GHz and man-made noise decreases with increasing frequency. McHenry explained that the received signal weakens with the square of the frequency, but if the receiver is close enough to the source, it will still hear it.

*Inside versus outside measurements*: McHenry noted that there is much more noise indoors than outdoors because of the cumulative effect from many unintended radiators indoors.[6] Matheson added that noise is also worse indoors because wires in indoor devices act like antennas and re-radiate emissions. Further, Sanders observed that many sources of radiation originate indoors and suggested that there needs to be more studies examining indoor noise. McHenry noted that although indoor noise has been measured less often than outdoor noise, the U.S. Army has expressed concern about outdoor noise causing harmful interference, calling it "encroachment."

**(3) *Interpretation of measurements***

---

[5] The received signal weakens with the square of the frequency, but if a receiver is close enough to the noise source, the receiver will still going to hear the noise source. Today, the probability is greater that the receiver will be close to a noise source since cellphones, tablet computers, etc. are portable and carried on one's person.

[6] Slides presented by Mark McHenry are available at http://www.silicon-flatirons.org/documents/conferences/2013-11-14%20Spectrum/McHenry%20Measurements%20%20Presentation%20%20v1.pdf.

*Basics of interpreting measurement data*: The panel agreed that the method of testing must be considered when drawing conclusions about measurements. For example, mobile measurements are difficult to interpret because transmitters can be in many places, said McHenry. He cautioned that for this and other reasons, it is easy to take bad measurements, which leads to bad data.

*Cumulative effects of noise and the aggregation effect*: Wepman argued that the most important consideration in taking noise measurements at frequencies higher than those where man-made noise is significant is aggregate emissions from multiple sources.

**(4) *Policy and implications of noise measurements***

*Problems for regulators in noise measurements*: McHenry said that the main issue is that we do not know what the problem is right now; we need testing and analysis to determine whether there are widespread noise interference problems and, importantly, whether the problems violate regulations. Although Matheson suggested that Wi-Fi at high frequencies is resilient because transmitters are close together and are increasingly getting closer, De Vries suggested that adding more transmitters increases noise. An audience commenter suggested that the worst offenders of noise pollution are high efficiency fluorescent light ballasts, switching power supplies, and sports scoreboards.

*The regulator's role in addressing noise measurement problems*: McHenry asserted that the FCC should be responsible for addressing issues of noise and interference. Additionally, he said that co-channel interference should be dealt with by simply changing channels, which will become cheaper over time. Sanders said current limits reflect the existing state of the art for devices on the market; he stressed that regulators must consider what is economically viable. Additionally, Sanders argued that noise is not always bad; for example, signals from microwave ovens can be used to verify that testing devices are working.

*Funding noise measurements*: De Vries noted that while there are many good studies, they are in limited areas, and it is difficult to get funds from the government for more comprehensive studies. McHenry countered that a comprehensive study of noise measurements everywhere is not necessary; instead, he argued that the industry must focus on taking measurements only where interference problems arise.

*Ex-post versus ex-ante enforcement*: It is difficult to find a source of interference, and it is even harder to compile evidence on an offending party causing interference. Thus, Hatfield questioned whether interference is infrequent enough to always be addressed by *ex-post* enforcement. He said that we need more data to determine whether there should be enforcement *ex-post* or *ex-ante*. Sanders pointed out that sometimes victims and offenders are completely in accord with all rules and regulations, providing the example of "GSM gallop" near microphones/speakers.[7] Accordingly, he asked whether devices should be examined for compatibility problems. Further, Sanders argued that it is simply not possible to develop tight enough limits to prevent all interference.

---

[7] *See* John Whalen, *Design How-To: Minimize GSM buzz noise in mobile phones*, EE Times University (July 20, 2009) http://www.eetimes.com/document.asp?doc_id=1276434.

*Role of carriers and sharing private data*: As a final note, Hatfield commented that cell phones have the capability of doing limited measurement and there are already millions of devices on the market that could achieve beneficial testing. Carriers are collecting useful noise measurement information, said Hatfield, and he suggested that carriers should be encouraged to share the information.

## Panel 2: Services and Scenarios

***Panelists****: Lynn Claudy, Senior Vice President, Technology, National Association of Broadcasters; Thomas Dombrowsky, Engineering Consultant, Wiley Rein LLP; Mark Gibson, Senior Director, Business Development, Comsearch; Dale Hatfield, Spectrum Initiative Co-Director, Senior Adjunct Fellow, Silicon Flatirons Center, Adjunct Professor, University of Colorado; Matt Larsen, Vistabeam; and Steve Sharkey, Director, Chief Engineering and Technology Policy, Government Affairs, T-Mobile USA.* ***Moderator****: Ari Fitzgerald, Partner, Hogan Lovells US LLP.*

Panel 2 discussed the types and levels of noise pollution that service providers and other users are observing in the field and the trends associated with those observations. Specifically, the panelists discussed (1) the problems and implications of noise, (2) solutions to noise problems, and (3) practical implementation of noise improvement methods.

### (1) *The problems and implications of noise*

*Harmful interference definition*: There was a consensus that harmful interference is hard to define. Sharkey suggested that interference is obviously harmful if it shuts down a device, but some noise may not be harmful and some use is often better than no use. For Sharkey, the goal is for spectrum to eventually become cleaner and cleaner.

*Interference issues affecting broadcasters and cellular providers*: Claudy noted that interference and the noise floor is a moving target. For example, he observed that the shift from analog to digital broadcasting shifted the preference landscape for users. The problem, he said, is that spectrum sharing and use of TV white space raise serious interference concerns, and he questioned what the highest and best use of a particular spectrum band might be. For example, he said we now care more about impulse noise for digital television service in the low VHF band than we did in the analog television era. Sharkey added that a main interference problem for cellular is clearing government users from reallocated spectrum, citing that there is a wide mix of government spectrum use across the country—especially by the Department of Defense (DOD) and the Department of Justice (DOJ). Sharkey explained that sometimes, after the government claims to be off a spectrum band, T-Mobile discovers interference after its network are deployed. In these instances, he explained that T-Mobile has to triangulate interference signals, take pictures, and alert the offending agency in order to solve the problem. Another issue is that law enforcement sometimes deploys old, off-the-shelf equipment that can bring down a local cellular network. In conclusion, Sharkey argued that 1755-1780/2155-2180 MHz AWS (advanced wireless service) spectrum deployment, the lower portion of which is currently used by the federal government, will require a more complex interference analysis—the question, he said, will be what level of impairment is acceptable. He said these problems arise during transitions. Additionally, he noted that there will be more sharing and more DOD and other federal systems will remain in the band, so there will need to be more coordination. Finally, he said that these issues bring up the question, yet again, of the definition of harmful interference.

*Interference issues in unlicensed use*: Larson explained that unlicensed users have no right to be free from interference, so the devices must be robust enough to withstand interference and must be able to navigate interference in order to survive. As an example, he pointed out that software defined radios (SDR) have spectrum flexibility. Larsen said that because of the robust nature of unlicensed devices, the some causes of unlicensed interference are lightning and FM radio that affect Ethernet wires on the towers. Larsen said SDR is used to resolve these issues. He also identified other remedies, including reducing the size of the cells and using high-gain antennas on customer premises to maintain a high signal-to-noise ratio.

*Unlicensed interference case study*: Larsen told the story of a WISP-delivered Internet service that was not working well because a neighbor's cordless phone was interfering. This, he explained, is rare now because the system is more robust. However, it provides an example that systems degrade as unlicensed spectrum availability decreases, and we need better approaches for unlicensed user coordination than the current honor system, where he said, there is "mutually ensured destruction." For example, he suggested that an improved business model would include more lightly licensed spectrum, allowing for more coordination and sharing. Fitzgerald commented that Larsen's suggestion was interesting given that Larsen's business model in the past has depended on the unlicensed nature of spectrum.

*Incumbent service complaints*: Dombrowsky explained that incumbents are very defensive about operations on their licensed spectrum and believe they need a clear and free link margin. For example, the increase in the noise floor experienced by GPS needs to be taken in account as the FCC imposes out of band limits for new wireless services in the vicinity—the outcomes will impact wireless operators, said Dombowsky. Importantly, after the success against LightSquared,[8] GPS and other incumbents feel more empowered to complain about interference from operators on bands that are farther away spectrally from the GPS band.

*Aggregation issues*: Gibson noted that aggregation of signals causing interference is a problem because aggregation is very hard to mitigate because of the "one more player tipping the apple cart problem." Dombrowsky agreed, saying that while the first-in-time (or last player in) concept resolves some problems, now that spectrum use is so complex, that solution is less effective. Gibson added that it is very hard to deal with all players equitably.

**(2) *Solutions to noise problems***

*Deployment management*: Part 101 of the FCC rules (which applies to certain terrestrial microwave services) has required frequency coordination before licensing and deployment since the 1970s. Gibson explained the process. First, the license application must include a supplemental showing of successful coordination. Then, the coordinator sends information out to other licensees and performs coordination. About 99.9% of the time, everything works well, and the remaining uncoordinated users are flagged for review. However, for the rare cases of interference, the coordinator will troubleshoot (over the phone or send a truck if necessary) and will use available tools to mitigate the interference. This process has worked well in the band for 40 years. However, replication of this approach in other bands is highly dependent on the new band's characteristics and users. Moreover, the following question must be asked: What is interference and is the complaining party really experiencing interference?

---

[8] For more information on LightSquared, *see* http://en.wikipedia.org/wiki/LightSquared.

*Receiver performance standards*: Knowingly ignoring the issue that the FCC may not have jurisdiction over receiver performance, Dombrowsky stated that at this point, resolution of noise interference problems will require action on receiver performance. While Sharkey acknowledged that there is support for the FCC to do something about receiver performance in general, he urged that the focus should not just be on receivers, but that it should also be on the network as a whole. He said there must be a balance between receiving low level signals and network robustness. A good example of balance, he said, is the standards for 800 MHz and public safety; here, the FCC has defined an environment for operation—if there is interference and the rules are being followed, the victim receiver has to adjust. Further, Gibson noted that the FCC has antenna standards in some areas, and the FCC could build receiver standards on this precedent. Sharkey also said that standards should be industry driven, but Claudy said that regulating receivers is a non-starter in industry conversations. Dombrowsky agreed that it is expected and typical that incumbents do not want receiver standards applicable to operations in their bands. Gibson explained that for legacy operators, receiver standards could implicate public interest issues. Claudy added that receiver standards are not popular or realistic in legacy bands. In new bands, he said, receiver standards may be applicable, but with legacy equipment, trying to replace the equipment is too costly. Dombrowsky pointed out that receiver standards are increasingly desirable because "we have run out of easy [ways]" to resolve spectrum congestion. Further, he observed that the government cannot keep up with technology and evolving standards, and the commercial sector needs to advise the government on how to work productively to get more use out of standards. “There needs to be a political will to implement a transition to the receiver side and the sooner the issue is thought about and acted upon the better,” he said. Gibson agreed that the industry has run out of easy solutions against interference and in the face of the spectrum crunch, hard decisions must be made.

*Harm claim threshold regulation*: Claudy suggested that harm claim threshold standards would not draw as much industry opposition as receiver standards. Hatfield explained that the advantage of harm claim thresholds is that the FCC can dictate thresholds and let the industry determine technical tradeoffs and equipment standards. He proposed that the FCC could use a 10-year timeframe for imposition of new thresholds to allow the natural phasing out of old technology. The abstraction of interference limits will allow design engineers to design a device that works because of the better description of the environment. Others agreed that harm claim thresholds might be a viable option. First, there are already antenna standards in some bands. Second, as Gibson pointed out, commenters on harm claim thresholds are not saying "no way, no how," but instead they are saying, "not in my band," which is better than the reaction to receiver standards. Claudy observed that harm claim thresholds regulate receiver standards without drawing as much industry opposition—importantly, De Vries made clear that harm claim thresholds are not setting receiving standards at all but are an entirely different standard.

*Case-by-case approach to interference resolution*: The panelists agreed that regulation must be based on a case-by-case approach. Gibson rehashed that, for example, sharing could be more successful with receiver standards in some new bands, but where there is legacy equipment, receiver standards are too costly. Another example is in hospitals, where devices are very old because hospitals often repurpose devices to keep costs down, so it would be costly to impose receiver standards. Sharkey added that where receivers are not tied to the service provider, such as in broadcast and consumer services, there are more issues with optimal system operation. Sharkey underscored that new systems use spectrum more efficiently all the way down to the noise floor and as times change, there are huge improvements in capabilities of equipment. Larsen agreed that in 4-7 years, the industry will see natural selection remove less efficient, obsolete technology.

**(3) *Practical implementation of noise improvement methods***

*Defining harmful interference*: Dombrowsky emphasized that whether interference is harmful depends on the players and the situation. Sharkey added that the issue is constantly becoming more complicated and the big question now is whether any negative impact (any interference) is harmful interference—if a link still works, is there harmful interference, he asked. Additionally, Dombrowsky said that defining harmful interference might not be the right goal because there is constant and drastic change in the industry—"Many oxen are gored when trying to create a legal definition of harmful interference," he said. He recognized that definitions can work well when dealing with similar services, but he argued that definitions cause problems in inter-service disputes.

*Government and private sector involvement in interference standards and disputes*: Dombrowsky pointed out that the FCC decided not to attempt to define harmful interference because it was too complex and case-by-case specific. Gibson suggested that instead of the FCC imposing a definition on the industry, the standard should be mutually agreed upon by the industry—"it should be industry or standards body specific, not FCC/regulator imposed," he said. Hatfield agreed, noting that the possibility of retaliation constrains behavior, but he observed that there must be the possibility of retaliation for this effect to take place. Sharkey highlighted the need to ensure coordination between users. Sharkey said that because of constant interference problems in the field, users must work with other carriers to resolve problems and must open lines of communication with one another. Sharkey said that 90 percent of the time users can work interference issues out, but the role of the regulator is to arbitrate the other 10 percent of the time.

Finally, Sharkey suggested that harm claim threshold standards are a good solution to guard bands that are diminishing with more use. Dombrowsky offered that out of band emission limits and other rules already serve the purpose of harmful interference thresholds; however, the key will be building certainty and flexibility into harmful interference standards. He gave the example that the definition of analog was easily agreed upon between coordinators, while digital definition is determined through analysis tools—regulators must know what the noise budget is and when another player will cause too much interference.

## Panel 3: Lessons from Environmental Pollution

***Panelists:*** *William Boyd, Associate Professor of Law, University of Colorado; John Dooley, Managing Director, Jarvinian; Dale Hatfield, Spectrum Initiative Co-Director, Senior Adjunct Fellow, Silicon Flatirons Center, Adjunct Professor, University of Colorado; and Vickie Patton, General Counsel, Environmental Defense Fund.* ***Moderator:*** *Phil Weiser, Dean, University of Colorado Law School, Executive Director, Silicon Flatirons Center.*

The third panel, "Lessons from Environmental Pollution," congregated a unique interdisciplinary panel directed at comparing and contrasting approaches used to control other forms of pollution (e.g., water and air) with those used in protecting the radio spectrum environment. The panel explored (1) Coase applied to environmental and radio noise emissions, (2) command-and-control and cap-and-trade solutions to emissions problems, and (3) translating environment models to spectrum policy.

**(1*) Coase applied to environmental and radio noise emissions***

*Coase*: Weiser began the panel discussion with an introduction to Coase, explaining that in 1959, Coase wrote articles advocating that the FCC should define spectrum rights and that spectrum should be distributed by auction. According to Coase, 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. This can be distinguished from the Pigovian Theory, which uses taxation to punish bad behavior—where bad behavior is pollution or interference.

*Coase in action*: Boyd stated that recent market-based approaches to environmental pollution control are largely inspired by Coasean principles.

**(2) *Cap-and-trade solutions to emissions problems***

*Cap-and-trade*: Patton began by detailing the *ex-post* approach of cap-and-trade for addressing environmental pollution. She explained that environmentalists pulled together to establish science-based limits to protect the commons and allow market forces to attenuate emissions through cap-and-trade regulation.

*Rights incentive in the cap-and-trade model*: Patton argued that the cap-and-trade approach does not give actors the right to pollute; rather, it incentivizes social protections through cost minimization. The approach emphasizes entitlement and rights, aligning incentives with social goods. Importantly, the system was developed by looking at distribution effects (a progressive view), focusing on communities that were not able trade effectively.

*California's cap-and-trade initiative as a model*: Patton highlighted a policy in California as an example of a successful progressive environmental policy. She explained that in California, large emitters are allowed to trade carbon credits to achieve limits and credits are distributed by auction—a practice that generates income for the communities who often bear disparate impacts of environmental degradation. Boyd noted that the California cap-and-trade program adopted a liability framework for fraudulent reporting and trading by buyers as well as significant penalties for non-compliance.

*Measurement and transparency in cap-and-trade initiatives*: Boyd noted that while cap-and-trade initiatives have led to reductions in emissions that create acid rain, the system has not always worked as well as it could because of design flaws. Specifically, Boyd argued that cap-and-trade systems often lack necessary attention to measurements. Boyd explained that successful and effective models of cap-and-trade regulation must define and measure an asset class. Accordingly, he pointed to the incorporation of continuous emission monitoring systems in regulation as an essential measure that led to the $SO_2$ Amendments.

*Point source versus ambient pollution*: Traditionally, in spectrum there was a focus on point sources of interference, but the focus is now shifting towards ambient pollution (including in this conference). Environmental regulation provides an example of two regulatory regimes that went different ways—water regulation went from focusing on point source pollution to ambient source pollution, while air went from focusing on ambient source pollution to point source pollution.

*Transparency*: Expanding on an issue discussed in Panel 2, Patton added that in addition to better measurements, disclosure requirements are important. Patton said that the "side effect of transparency" is that people start releasing information and "discover all sorts of pollution going on that was not known before."

*Market-driven approach in spectrum regulation*: Hatfield noted that the market-driven approach in telecommunications has facilitated desirable transactions in spectrum allocation. Hatfield explained that while spectrum trading did not develop to the extent anticipated, the market-driven approach had unanticipated application and has allowed companies to lease spectrum while awaiting FCC clearance.

***(3) Translating environment models to spectrum policy***

*The role of receivers*: Dooley discussed improving receiver health to mitigate radio emissions. Dooley explained that spectrum is a very small resource with a commons, consisting of only 3GHz, and argued that receivers can be a limiting factor. He pointed to the LightSquared/GPS problem as an example of a grave interference problem because boundaries on the types of services used were not established. While receiver standards and enforcement are important, he recognized that they are not the panacea for all situations, noting that selective screens on receivers not only exclude unwanted signals but also attenuate desired signals.

*The aggregation problem of pollution*: Patton spoke about how environmentalists have addressed the aggregation problem of pollution. Patton argued that the best way to address pollution caused from an aggregate of sources is to gather extensive information and establish limits based on scientific evidence. Patton used world fishery regulation as an example of how, with limits based in scientific data, market forces can be used to successfully mitigate environmental problems.

*Establishing viable standards*: Boyd reiterated that flexible standards based on science are essential in establishing viable standards. Boyd supported Patton's argument by pointing to the National Ambient Air Quality Standards within the Clean Air Act that establish health-based standards for criteria pollutants. Under the National Ambient Air Quality Standards, an administrator sets national standards (within a margin of safety) and then gives states the power to determine how to adhere to the national standards within the state. Weiser noted that the use of data has not always been conducive to good policy in telecommunications and pointed to the "Low Power FM" story as an example of how lobbyist were able to use misleading data based on extreme situations in isolated areas to overturn an FCC decision.[9]

*Translating environmental models to spectrum*: Dooley noted that successful models addressing environmental pollution might not translate well to radio emissions. First, he explained that public outcry is likely to be greater for environmental degradation than for spectrum interference. Because spectrum pollution is less visible than environmental pollution, he argued that decisions are likely to be made by license holders and other interested parties rather than the public-at-large or a disinterested third party. Accordingly, he asserted that it might be more difficult to

[9] *See FCC's Low Power FM: A Review of the FCC's Spectrum Management Responsibilities: Hearing Before the Subcommittee on Telecommunications, Trade, and Consumer Protection, House of Representatives*, 106th Cong. Washington, D.C.: United States Government Printing Office, 2000, *available at* http://www.gpo.gov/fdsys/pkg/CHRG-106hhrg62973/html/CHRG-106hhrg62973.htm.

attain a holistic view and address radio noise issues. Second, he asserted that in the environmental paradigm, new technology often brings cleaner environmental solutions (such as renewable energy). He explained that in telecommunications, new technology means greater demand on spectrum and exacerbates the interference problem. He suggested that despite these dissimilarities, the best course to address this issue is to begin charting the spectrum interference problem. Boyd responded to Dooley's claim that environmental pollution is more visible than spectrum pollution, saying that while some environmental pollution is visible, other environmental pollution is not visible, and it is a similarly difficult problem to address.

*International solutions to environmental pollution*: Patton answered an audience question that asked about international solutions to environmental pollution. Patton pointed to coalitions and multinational and bi-national approaches to climate change and cited the work by Professor Michael Vandenbergh,[10] at Vanderbilt University, as a compelling argument for how the private sector can align to address environmental problems.

*Academic institutions and decision making*: A second question from the audience asked panelists to speak on the extent that the Scientific Advisory Board of Academics is used in EPA deliberation and noted that, unlike the EPA, the FCC is dominated by industry experts who are not involved in ongoing rule making. Boyd used the Dioxin risk-reassessment as an example of how the Scientific Advisory Board has played an enormous role in informing EPA's regulatory efforts.

*Lessons learned and spectrum solutions*: Weiser concluded by explaining that Coase theorized that property rights (or the "harmful interference" standard for spectrum) should be specifically defined and that transaction costs should be lowered. Weiser suggested that class action solutions, increased transparency for receivers, and other means to provide for collective trade may prove to be compelling solutions for the spectrum interference problem.

**Panel 4: Enforcement & Policy Initiatives**

***Panelists:*** *Rebecca Dorch, Director, Western Region, FCC, Enforcement Bureau; ; Dale Hatfield, Spectrum Initiative Co-Director, Senior Adjunct Fellow, Silicon Flatirons Center, Adjunct Professor, University of Colorado; Mitchell Lazarus, Attorney, Fletcher, Heald & Hildreth, P.L.C.; Paul Margie, Partner, Wiltshire & Grannis LLP; and David Solomon, Partner, Wilkinson Barker Knauer, LLP.* ***Moderator:*** *Chris Guttman-McCabe, Executive Vice President, CTIA – The Wireless Association.*

The fourth and final panel explored tools available, in terms of both processes and advanced systems, for improving enforcement and where the associated priorities should be focused. Panelists discussed (1) trends in interference enforcement, (2) Enforcement Bureau processes and procedures, (3) ensuring compliance with device standards, (4) and the goals of spectrum enforcement.

**(1) *Trends in interference enforcement***

*Increasing number of devices*: Lazarus stated that there are a "skyrocketing number of devices but decreasing interference problems." He explained that while there are many more sources of

[10] http://law.vanderbilt.edu/bio/michael-vandenbergh.

interference, individually, each source is interfering less. Margie agreed, saying that although many unlicensed users say the noise floor is increasing, that the noise floor may not be the primary challenge; instead, he said, the interference problems arise because there are so many more users and so much more technical diversity all competing for the same channels. With this noted, Margie argued that having a huge number of devices is a good thing—"It is the result of lots of innovation and use and therefore more utility for everyone," he said.

*Device taxonomy and foci of enforcement*: Lazarus asserted that manufacturers do not have many issues designing receivers that tolerate noise. The focus, he argued, should be on these technological capabilities because many interference-causing devices are actually highly beneficial to consumers, and the incumbents should deal with the interference. In other words, rights must account for social value, he said. Solomon agreed that "good problems" have arisen with the increase in the number of devices, but he cautioned that the reality of these problems (including mobile, diffuse, and combined uses causing interference) make the FCC's interference detection job a lot more complicated.

*Scientific understanding of interference problems*: Hatfield stated that the scientific understanding of interference problems is eroding, which is escalating the need for more measurements. Hatfield supported this by explaining that most complaints of interference are anecdotal. Thus, he said that the main takeaway from this conference should be that we need more scientific-based information in order to make good decisions. Hatfield poised the question, "is the problem getting worse in certain areas and not others?" He points to noise from car ignition systems as an example of a noise source that is declining while other sources are increasing.

**(2) *Enforcement Bureau processes and procedures***

*Enforcement Bureau basics and tools*: Dorch explained that, for interference resolution and enforcement, the Enforcement Bureau's field organization employs primarily engineers and uses multi-functional measurement equipment and tools during on-scene investigations. The process for interference complaints is as follows: the Enforcement Bureau field agents investigate complaints of interference, with priority given first to interference complaints from public safety entities and then from critical infrastructure (such as mass transit, water systems, pipelines, etc.). Then the Enforcement Bureau uses monetary and non-monetary sanctions, citations, and warnings to enforce the FCC's technical rules, gain compliance, encourage good behavior, and also to ensure equipment and devices are appropriately certified for sale or use. Dorch explained that the Enforcement Bureau field agents often start enforcement with a warning (oral or written), which usually resolves the problem. Solomon added that if a warning does not resolve the problem, the most common action is a civil penalty (fine); in the most serious cases, the DOJ takes criminal action and the FCC can issue cease and desist orders. Additionally, Dorch noted that lately, the Enforcement Bureau has received an increasing number of interference complaints for Part 15 and Part 18 devices.

*Justifications for government intervention and incentives for self-policing*: De Vries asked the panel whether there was some kind of externality, for example that parties' interests do not align, that justifies government regulation. Additionally, he observed that because the noise floor is rising for everybody, there is not enough incentive for any individual operator to solve the problem. However, carriers have a lot of interference data, and De Vries proposed that they should be required to share it, posing the question, "how can carriers be encouraged to share the data?"

*Decline in FCC resourcing and resultant capability*: Margie stressed that Congress needs to recognize that increasing the FCC budget in some areas will have huge benefits, stating that the FCC needs resources to experiment in order to determine the best way to address interference. He said there is a "huge tidal wave of new devices and complexity of devices," and the FCC may be able to simplify the certification and enforcement process but needs resources to do the necessary tests. Solomon agreed that resource constraints are a serious issue—citing that the EPA has 6,000 scientists[11] and the FCC has less than 2,000 employees,[12] not to mention that the Field is only a part of the Enforcement Bureau and an even smaller part of the FCC.[13] Finally, as an aside, Margie asked, "Why aren't more FCC staffers considered critical during a government shutdown?" He noted that when the FCC lab closes during a government shutdown, there are serious consequences for large parts of the economy.

**(3) *Ensuring compliance with device standards***

*Techniques to ensure device compliance standards*: Dorch noted that the certification process has allowed the enormous proliferation of devices. Additionally, she noted that when a device causes interference, many tactics can be used to resolve the issues. Lazarus pointed out that companies that certify for the FCC spot check a certain number of certified devices every year, ensuring that they are in compliance with the rules. Solomon said that the FCC needs new models with private industry assistance to ensure compliance.

*Incentivizing device manufactures to build robust interference protection*: Hatfield suggested that harm claim thresholds would help device manufacturers know how to make their devices in order to avoid interference. Margie cautioned that because sometimes receivers are better than they say they are, the FCC should look at assumptions behind interference standards—he noted that manufacturers may have the ability or incentive to characterize their devices as "egg shell skull receivers." Hatfield reiterated that interference is a critical issue and is hampered by the FCC's lack of resources, but issues, such as GPS jammers, need to be addressed.

*Incentivizing non-telecom device manufacturers to reduce harmful radiation*: Hatfield observed that even though ISM devices are exempt under Part 15, in some instances they still emit harmful interference to radio devices, and he argued that the FCC needs more facts and information about this interference. He thinks that the facts and information exist in the industry already, and

[11] Letter to the Honorable Lisa P. Jackson, Administrator, U.S. Environmental Protection Agency, *Science Integration for Decision Making at the U.S. Environmental Protection Agency*, United States Environmental Protection Agency, Washington D.C. at 2 (July 6, 2012), *available at* http://yosemite.epa.gov/sab%5CSABPRODUCT.NSF/8AA27AA419B1D41385257A330064A479/$File/EPA-SAB-12-008-unsigned.pdf.

[12] As of 2012, the Federal Communications Commission had 1,898 full time employees. *Fiscal Year 2012 Budget Estimates Submitted to Congress,* Federal Communications Committee (Feburary 2011), *available at* http://hraunfoss.fcc.gov/edocs_public/attachmatch/DOC-304636A1.pdf.

[13] *See* GAO Report to Congressional Requesters, *FCC Management: Improvements Needed in Communication, Decision-Making Processes, and Workforce Planning*, GAO-10-79 (December 2009) ("From fiscal year 2003 to 2007, the number of engineers at FCC decreased by 10 percent, from 310 to 280.").

serious thought needs to go toward determining the best way to get this information to the FCC and academics.

*Creating a simple, workable approach—automation and crowdsourcing*: A member of the audience asked whether automated systems could be effective in helping mitigate interference. Guttman-McCabe responded that this would create opportunities for information gathering. Hatfield added that crowdsourcing is an opportunity as an enhanced, cost effective method.

*Balancing the impact and benefit of new services:* Solomon stated that staff membes at the Office of Engineering and Technology are looking at benefits of new services and how much impact on existing service is appropriate. He said that the staff at the FCC approaches the issue objectively and professionally but there are externalities, namely lobbying, that can slow things down and complicate them.

**(4) *Goals of enforcement***

*Balance between protecting lawful users and permitting innovative flexibility of use*: Margie suggested that it might be practical to address the issues of noise floor and other interference issues separately. Lazarus stressed balance, giving the example of an increase in interference for amateur radio operators that is justified by the large social value of new use. The challenge, he said, is negotiating—acknowledging that every band has entrenched incumbents. He said that reasonable incumbents in the past include two players: fixed wireless and radio astronomy. To conclude, Lazarus said that we must ask the following three questions of any proposed use of spectrum that requires a rule change: first, why is this a good thing (social value); second, why is it not a bad thing (limited interference); and third, why can't it be done under the existing rules?

*Interference pros and cons*: Margie concluded the conference by drawing the big picture; non-intentional radiators (such as lights, power supplies, and routers) are the biggest contributors to the noise floor, he said. Furthermore, he said the bigger issue is what co-channel constraints are being created by the increasing number of devices rather than overall noise floor increases due to non-intentional radiators. Echoing discussions in the conference, Margie highlighted the need for a balance between value of new technology with existing technology, stating that the goal should be to maximize utility not to minimize interference and to find additional licensed and unlicensed spectrum to account for increased demand (as an example, he described the opportunities at the 5 GHz UNII-1 band).

## Conclusion: Why Radio Spectrum Pollution Matters

The conference covered a range of issues about radio noise and came to the following conclusions. First, strong evidence suggests that the noise floor is raising in higher frequency bands that are critical to many wireless systems; yet, the scope of the problem is largely unknown because much of this evidence is anecdotal. Second, even when scientifically valid measurements are made, the measurements often lack transparency and are not systematic.

Thus, 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. Further, better disclosure and transparency of gathered information about noise pollution will allow the industry, academics, and policymakers to identify emerging sources of noise pollution and to develop strategies and processes for dealing with the more egregious sources of noise pollution.

As discussed in this report, throughout the conference, the assembled academics, participants, and professionals in the industry identified several issues in noise interference and suggested solutions; however, the question remains, why does radio spectrum pollution matter? Accordingly, the panelists explored the idea that increased transparency and disclosure on gathered noise floor data is justified by the impact that increased noise pollution can have on social and economic value of the radio spectrum resource.

An answer to the why care question came in a comment made by a member of the audience, Scott Townley, a Verizon engineer. Mr. Townley said that as an engineer, he cannot recommend that Verizon value the 600 MHz band at the same valuation as the 700 MHz band. Mr. Townley explained that there is a divergence in valuation between the two bands because the companies now have a lot of measurements confirming an elevated noise floor. This statement validates the point that noise pollution must be taken seriously.

In essence, Mr. Townley's comment affirms that noise pollution impacts the economic and social value of the radio spectrum resource and lays out why the industry and regulators should pay attention to, study, and invest in reducing the rising noise floor. Specifically, his comment confirms that companies like Verizon will base their valuation of a spectrum band on the amount of noise pollution in that band.

The government is receiving billions of dollars for spectrum and the government wants to be paid billions more. Noise interference at some frequencies (for now, at lower frequencies) will decrease the value of those bands. Accordingly, Hatfield explained that if the base value of spectrum is set at tens of billions of dollars, (assuming impairment is just 10 percent--and it is likely more) the cost of noise pollution will be in the tens of millions of dollars.