

In the Matter of)
) GN Docket No. 09-51
A National Broadband Plan for Our Future)

The National Academy of Sciences, through the National Research Council's Committee on Radio Frequencies (hereinafter, CORF¹), hereby submits its reply comments in response to the Commission's April 8, 2009, Notice of Inquiry in the above-captioned docket (NOI). Herein, CORF addresses issues raised in paragraph 44 of the NOI regarding a proposed "spectrum inventory" and discusses the need to recognize and protect the passive scientific use of the spectrum in connection with any such inventory. CORF also addresses the potential impact of cognitive radio technologies on passive scientific use of the spectrum.

CORF has a substantial interest in the spectrum issues raised in this proceeding, because CORF represents the interests of the passive scientific users of the radio spectrum, including users of the Radio Astronomy Service

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(RAS) and Earth Exploration Satellite Service (EESS) bands. RAS and EESS observers perform extremely important yet vulnerable research and provide data of national importance.

As the Commission has long recognized, radio astronomy is a vitally important tool used by scientists to study our universe. It was through the use of radio astronomy that scientists discovered the first planets outside the solar system, circling a distant pulsar. Radio astronomy has also enabled the discovery of organic matter and prebiotic molecules outside our solar system, leading to new insights into the potential existence of life elsewhere in our galaxy. Measurements of radio spectral line emission have identified and characterized the birth sites of stars in our own galaxy, the processes by which stars slowly die, and the complex distribution and evolution of galaxies in the universe. Radio astronomy measurements have discovered fluctuations in the cosmic microwave background, generated in the early universe, which later formed the stars and galaxies we know today. It has established the existence of a black hole in our galactic center, a phenomenon that may be crucial to galaxy formation. Observations of supernovas have allowed researchers to witness the creation and distribution of heavy elements essential to the formation of planets like Earth, and of life itself.

The Commission has also long recognized that satellite remote sensing, including sensing by users of the EESS, is a critical and unique resource for monitoring aspects of the global atmosphere, land, and oceans. For certain applications, satellite-based microwave remote sensing represents the only

practical method of obtaining atmospheric and surface data for the entire planet. EESS data have contributed substantially to the study of meteorology, atmospheric chemistry, climatology, and oceanography. Currently, instruments operating in the EESS bands provide regular and reliable quantitative atmospheric, oceanic, and land measurements to support a broad variety of scientific, commercial, and government (civil and military) data users. Major governmental users of EESS data include the National Oceanic and Atmospheric Administration (NOAA), the National Science Foundation, the National Aeronautics and Space Administration (NASA), the Department of Defense (especially the U.S. Navy), the Department of Agriculture, the U.S. Geological Survey, the Agency for International Development, the Federal Emergency Management Agency, and the Forestry Service. Applications of the data include weather forecasts for use in military and civilian aviation and sailing; hurricane and severe storm warning and tracking; flood monitoring; seasonal and interannual climate forecasts and monitoring; observation and prediction of El Niño effects on agricultural production; studies of the ocean surface and internal structure; and monitoring of changes in vegetation cover, snow cover, and ozone holes, as well as many other critical areas. Use of EESS data is critical to the study of global climate change.

However, the critical science undertaken by RAS and EESS observers cannot be performed without access to interference-free spectrum. Furthermore, the emissions that radio astronomers receive are extremely weak—a radio telescope receives only about one-billionth of one-billionth of a watt (10^{-18} W)

from a typical cosmic object. Because radio astronomy receivers are designed to pick up such remarkably weak signals, radio observatories are particularly vulnerable to interference from in-band emissions, spurious and out-of-band emissions from licensed and unlicensed users of neighboring bands, and emissions that produce harmonic signals in the RAS bands. Even weak, distant in-band man-made emissions can preclude RAS use. Like radio astronomers, remote-sensing scientists have little control over the frequencies at which they must observe in order to fulfill their scientific missions — the specific frequencies of specific elements or molecules are established by the laws of physics and chemistry. Similarly, since remote-sensing scientists observe the noise floor itself and extremely weak variations therein, their observations are also very vulnerable to interference from man-made transmissions.

II. Passive Use of the Spectrum Constitutes “Use” of the Spectrum That Should Be Recognized in Any Spectrum Inventory.

In paragraph 44 of the NOI, the Commission asks questions regarding the “use” and “utilization” of the spectrum in connection with identifying spectrum bands that may be suitable for wireless broadband services. While it would be unfortunately easy to overlook the use of the spectrum for RAS and EESS observation, in any spectrum inventory it is essential for the Commission to recognize that passive scientific use of the spectrum constitutes both “use” and “utilization.” Recognition of this fact in any spectrum inventory would be consistent with the existing and wide recognition of the passive use of spectrum elsewhere in domestic and international rules.

As was noted on page 2 of the Comments filed in this proceeding by the National Radio Astronomy Observatory, active transmission of signals is not the only way that the spectrum is used—the spectrum is often used for passive scientific observation as well.² Such use has wide regulatory recognition. The numerous allocations to RAS and EESS in the domestic and international tables of allocations demonstrate that the Federal Communications Commission (FCC) and the International Telecommunications Union both recognize that RAS and EESS constitute use of the spectrum equal to that of active services. Indeed, many of the allocations to RAS and EESS are as the primary and sole service in that particular band. See, e.g., the Table of Allocations in Section 2.106 of the Commission's rules at 73-74.6 MHz, 1400-1427 MHz, 1660.5-1668.4 MHz, 2690-2700 MHz, and 4990-5000 MHz.

In addition to frequency allocations, the FCC has recognized the importance of passive use of the spectrum in other regulations. Examples of geographic protection include Section 1.924(a) of the Commission's rules, which creates a National Radio Quiet Zone designed to protect the National Radio Astronomy Observatory in Green Bank, West Virginia, from interference. Section 1.924(d) of the Commission's rules similarly establishes notification requirements for a "Puerto Rico Coordination Zone" designed to protect radio astronomy at the Arecibo Observatory.³ Non-geographic-based protection for passive services is

² *Comments of the National Radio Astronomy Observatory In the Matter of A National Broadband Plan for Our Future*, filed June 1, 2009, available at http://fjallfoss.fcc.gov/prod/ecfs/retrieve.cgi?native_or_pdf=pdf&id_document=6520217839, last accessed July 15, 2009.

³ See also, *Amendment of the Commission's Rules to Establish a Radio Astronomy Coordination Zone in Puerto Rico*, Report and Order, 12 FCC Rcd 16522 (1997).

established in numerous other Commission rules. For example, Section 15.205 of the rules prohibits intentional emission of radiation from unlicensed devices in a number of bands allocated to passive services, including 13.36-13.41 MHz, 25.55-25.67 MHz, 38.0-38.25 MHz, 73-74.6 MHz, 401-403 MHz, 608-614 MHz, 1400-1427 MHz, 1660.5-1668.4 MHz, 2690-2700 MHz, 4.5-5.15 GHz, and 5.35-5.46 GHz.

III. Passive Scientific Observation is an Efficient and Valuable Use of the Spectrum.

Paragraph 44 of the NOI suggests that one purpose of any spectrum inventory would be to identify “underutilized” spectrum that could be used additionally for wireless broadband services. CORF is concerned that “underutilized” could be interpreted only in the context of active use to mean “any bandwidth not being used to transmit signals,” thus disregarding the protected passive bands needed for EESS and radio astronomy. The Commission should ensure that passive bands are considered and recognize that passive scientific observation is an efficient and valuable use of the spectrum.

A. *Passive Use Is an Efficient Use of the Spectrum.*

Scientific use of the RAS and EESS bands is done in a very spectrum-efficient manner. The natural sources of radiation measured by passive EESS applications are broadband and extremely low power relative to the signals generated and received by active services. As a result, observation over the entire allocated bandwidth is often required for accurate measurements.

Observed phenomena tend to be globally distributed as well, and observations are required on short time scales; given the number of EESS assets currently in

use, each point on Earth is observed in a passive allocation multiple times each day, 7 days per week.

The natural sources of radiation measured by passive RAS applications may be either broadband or narrowband. They are extremely low power relative to the signals generated and received by active services. The entire allocated bandwidth is usually needed for sufficiently sensitive observations of the broadband sources. The narrowband sources (e.g. the 1420 MHz emission line of neutral hydrogen) have varying apparent frequency depending on the motion of the emitting substance. Thus observations of the narrowband sources typically use the entire allocated bandwidth to measure the change with frequency of the emission line over the field of interest (e.g. a rotating galaxy). Radiotelescopes observe continually, are spread across all continents, and observe with extreme sensitivity over the entire allocated bandwidth. As a result, RAS' full use of the spectrum constitutes very efficient use of the spectrum.

It also should be noted that scientific observation in the passive bands constitutes efficient use in the sense that no observer prevents any other party from observing on the same frequency. Indeed, there is virtually no limit to the number of parties that can observe on the same frequency.

B. *Passive Use Is a Valuable Use of the Spectrum.*

The value of the science performed by passive users of the RAS and EESS bands can in some cases be measured directly, and in those cases, the value is very large. In other cases, the value of such science can be measured only indirectly, but that value is no smaller as a result.

1. *The Economic Value of Satellite Remote Sensing (EESS).*

Satellite remote sensing is one of the cornerstones of meteorology, oceanography, climatology, and environmental science, supporting analysis and research that provide assessments, forecasts, and warnings to the public. Weather- and climate-sensitive industries account for about a quarter of the U.S. gross domestic product. It has been estimated that the average impact on the U.S. economy of year-to-year weather and climate changes is \$100 billion in year-2007 dollars.⁴ Droughts, severe storms, and floods alone account for more than \$20 billion in damage annually in the United States. The impact on the U.S. economy of an El Niño event is estimated at \$25 billion.⁵ Without satellite remote sensing, the ability of the atmospheric and oceanic science community to monitor, analyze, and predict environmental conditions would be drastically diminished. These satellites provide a critical means of obtaining accurate and frequent assessments of certain aspects of land- and sea-surface and atmospheric conditions on a global scale.

The potential loss of any critical band for the EESS could be expected to result in significant costs to society, resulting from reduced ability to forecast weather and the environment, manage resources, and monitor and predict

⁴ See, Irving Leveson, *NPOESS Civil Benefits and Contributions to U.S. Economic and Environmental Security*, report to the NPOESS Integrated Program Office, April 24, 2007, pp. 21-22; as cited in Irving Leveson, *NPOESS Economic Benefits, Final Report*, June 18, 2008, p. 15 ("*Final Report*"), available at www.economics.noaa.gov/bibliography/npoess-report.doc, last accessed June 2, 2009. The value to the U.S. economy of the NPOESS program alone over its service life is estimated at approximately \$9 billion to \$16 billion in present-value dollars. *Final Report* at Table 4, p. 24.

⁵ Stanley A. Changnon, Gerald D. Bell, David Changnon, Vernon E. Kousky, Roger A. Pielke, Jr., and Lee Wilkins, *El Nino. 1997-1998: The Climate Event of the Century*, Oxford University Press, New York, 2000.

disruptive climate changes, both natural and anthropogenic. The costs of severe weather events alone are often in the hundreds of millions of dollars per event. NOAA's National Weather Service forecasts, warnings, and the associated emergency responses have been estimated to result in a \$3 billion savings in a typical hurricane season. Two-thirds of this savings, \$2 billion, is attributed to the reduction in hurricane-related deaths, and one-third of this savings, \$1 billion, is attributed to a reduction in property-related damage because of preparedness actions.⁶ Errors in temperature and precipitation forecasting for even benign meteorological events such as local or regional heat or cold waves can cost U.S. utilities approximately \$1 million per degree Fahrenheit daily as a result of an impaired ability to match energy supplies with demand.⁷ Similarly, benefits to U.S. agriculture by altering planting decisions based on improved El Niño forecasts have been estimated at \$265 million to \$300 million annually, throughout El Niño, normal, and La Niña years. Costs associated with errors in predicting the onset of regional climate changes could thus easily amount to hundreds of millions of dollars per year.⁸

While it is difficult to ascribe forecast errors to interference occurring within any specific microwave band, it is noted that undetected interference in any passive microwave band can seed the growth of large errors in numerical weather-prediction models. The costs of such forecasting errors are typically

⁶ National Oceanic and Atmospheric Administration, *Economic Statistics for NOAA*, 5th Ed., April 2006.

⁷ *Id.*

⁸ *Id.*

largest in areas of highest population density and thus of greatest spectral demand.

2. *The Value of Radio Astronomy*

The value of the radio astronomy performed by users of the RAS band must generally be measured more indirectly than that of satellite remote sensing, but that value is no smaller as a result. The scientific truths learned through radio astronomy about our universe—its origins, the physical forces that shape it, the prebiotic chemistry that occurs in it, and its ultimate destiny—are the priceless cultural heritage of all humanity. One measure of the value of radio astronomy is the four Nobel Prizes awarded for contributions to science made by radio astronomers.⁹ This includes awards for the discovery of the first pulsar in a binary system, leading to important confirmation of Einstein's theory of gravitational waves; and the discovery of the blackbody form and anisotropy of the cosmic microwave background radiation, which trace the fluctuations responsible for all of the structures seen in the universe.

3. *Spin-Off Technologies from the Passive Scientific Use of the Spectrum*

Value must also be attributed to the technologies developed to perform passive scientific observations that have been spun off to other uses. Because scientific discoveries are usually made at the limits of instrumental sensitivity, radio astronomy and satellite remote sensing have contributed significantly to the development of new technologies for medical, commercial, industrial, and

⁹ See, National Research Council, *Handbook of Frequency Allocations and Spectrum Protection for Scientific Uses*, The National Academies Press, Washington, D.C., 2007, p. 11.

defense purposes. Radio astronomy has been a copious source of transferable technology and algorithms, and of trained individuals interested in applying remote sensing and receiver expertise in a variety of sectors, especially telecommunications.¹⁰ Some examples are listed below:

- Originally developed as a radio astronomical technique for the high-resolution imaging of astronomical objects, very long baseline interferometry (VLBI) has been used for applications in Earth science—for example, the determination of geophysical parameters used in studying plate tectonics, polar wandering, latitude measurements, variations in Earth's rotation, and the identification of potential earthquake zones through the precise measurement of fault motion.
- The VLBI reference frame of celestial coordinates, based on extremely distant radio sources, is fundamental to the periodic calibration of the GPS reference clocks.
- Pulsar observations, VLBI, and applications of Einstein's general theory of relativity play a major role in precision navigation and geodesy—including that of spacecraft—and timekeeping.
- VLBI instrumentation is the source of the technology used to locate interference to commercial satellite uplinks.
- Astronomers played a significant role in refining the hydrogen maser clock, which is now an important frequency standard in applications requiring high-precision ($1:10^{15}$) frequency stability over periods of ~1000 seconds.
- Computerized x-ray tomography (CT scans) employs software and methods originally developed for mapping radio astronomy sources. The data-intensive computing and storage systems that are developed for signal processing in areas such as pulsar searches have wide applications elsewhere.
- Low noise receiver and signal analysis technology developed for radio astronomy has been used in implementing the Enhanced 911 emergency service.

¹⁰ National Research Council, *Working Papers: Astronomy and Astrophysics Panel Reports*, National Academy Press, Washington, D.C., 1991, p. 307.

- Development of millimeter and submillimeter radiation sources and detectors for radio astronomy has fostered the field of terahertz spectroscopy and its important Homeland Security applications in imaging and poisonous gas detection.

Radio astronomers have also adapted their methods of measuring microwave temperature for the noninvasive detection of tumors and other regions of vascular insufficiency. Microwaves have poorer angular resolution than infrared does but are more sensitive to deep-tissue temperatures. The combination of microwave and infrared thermographic data provides a true-positive detection rate of 96 percent, better than either alone, for breast cancer.¹¹

4. *Protecting Our Nation's Investment in Scientific Research*

Radio astronomy and satellite remote sensing require the operation of many facilities with different instruments and locations, including the vantage of space. This has required a significant financial investment by the federal government. Protecting this significant financial investment requires protecting the access to passive scientific service frequency bands that constitutes the purpose of the investment.

This investment in scientific research that uses the passive bands will certainly continue. For example, the United States plans to invest more than \$12 billion through the year 2026 in the National Polar-orbiting Operational Environmental Satellite System (NPOESS) program, to fulfill its critical weather forecasting and global climate monitoring mission.¹² Also, the United States

¹¹ National Research Council, *Working Papers: Astronomy and Astrophysics Panel Reports*, National Academy Press, Washington, D.C., 1991, p. 307.

¹² See, United States Government Accounting Office, *Environmental Satellite Acquisitions: Progress and Challenges*, GAO-07-1099T, July 11, 2007, Table 3;

continues to invest in radio astronomy observatories throughout the country, including upgrades such as the Expanded Very Large Array project, which is the largest upgrade ever to the world's premier radio telescope, the Very Large Array, in New Mexico. And President Obama has made it clear that increased investment in basic scientific research is an important goal in the current administration, stating that:

[a]t such a difficult moment, there are those who say we cannot afford to invest in science, that support for research is somehow a luxury at moments defined by necessities. I fundamentally disagree. Science is more essential for our prosperity, our security, our health, our environment, and our quality of life than it has ever been before.... We will devote more than 3 percent of our GDP to research and development ... [in basic and applied scientific research].¹³

As a return on the investment made by our nation, radio astronomy and satellite remote sensing have, over the past half century, made fundamental new discoveries and have brought us closer to understanding both the nature of the universe and that of our immediate environment. The benefits of that science will surely continue, but only if the radio-frequency bands for the passive services are protected.

highlights available at <http://www.gao.gov/highlights/d071099thigh.pdf>, last accessed on June 2, 2009.

¹³ Speech of President Barack Obama at the National Academy of Sciences Annual Meeting, April 27, 2009, available at http://www.whitehouse.gov/the_press_office/Remarks-by-the-President-at-the-National-Academy-of-Sciences-Annual-Meeting/, accessed June 2, 2009.

IV. The Operation of Cognitive Radios in the Passive Service Bands Would Create a Substantial Risk of Harmful Interference to Authorized Passive Users of the Spectrum.

In paragraph 44 of the NOI, the Commission seeks comments on the “extent [to which] new technologies such as cognitive radio [can] enable more efficient use of existing spectrum allocations or create new opportunities for sharing spectrum with existing services.” Although CORF commends the Commission for seeking more efficient use of the spectrum, it is deeply concerned that the basic cognitive radio concept ignores the existence of passive scientific users of the spectrum, and thus overlooks the substantial risk that cognitive radios would transmit on or too close to frequencies allocated to passive services. Such transmissions—and their associated out-of-band and spurious emissions, including harmonics—would increase the noise floor and cause harmful interference that would reduce or eliminate the utility of data obtained through scientific observation. This result would be inconsistent with the concept of efficient spectrum use, and contrary to the public interest.

A. *Protected Use of the Spectrum for Scientific Observation Cannot Be Detected by Dynamic Frequency Selection or Frequency Agility.*

One of the capabilities asserted of cognitive radios is frequency agility, which is the ability of a radio “to change its operating frequency, combined with a method to dynamically select the appropriate operating frequency based on the sensing of signals from other transmitters or some other method.” See, e.g., *In the Matter of Facilitating Opportunities for Flexible, Efficient, and Reliable Spectrum Use Employing Cognitive Radio Technologies*, Notice of Proposed

Rulemaking, 18 FCC Rcd 26859 (2003)(*Cognitive Radio NPRM*), at para. 22.

Similarly, the *Cognitive Radio NPRM* described a capability for dynamic frequency selection (DFS) as “a mechanism that dynamically detects signals from other radio frequency systems and avoids co-channel operation with those systems.”¹⁴ DFS and frequency agility are seen as the primary capabilities used by cognitive radios to avoid interference to incumbent authorized users of the spectrum. While CORF takes no position on the efficacy of such capabilities to sense the presence of active services, it is greatly concerned that *such capabilities, by definition, cannot sense the presence of passive observation of a frequency*. In the case of passive observation there is no identifiable “transmission” for cognitive radios to sense: the “transmission” being observed by scientists is in many cases nothing more than an extremely weak fluctuation in the noise floor.

In sum, CORF does not know of any practical cognitive radio sensing capability at this time that is capable of detecting the presence of passive observations. As a result, cognitive radios that rely solely on DFS or frequency agility capabilities to prevent interference cannot be expected to protect passive users of the spectrum from interference. Moreover, given their inability to protect passive use of the spectrum with these capabilities, cognitive radios transmitting on bands allocated to scientific use on a primary basis would be in violation of Part 15 principles, and contrary to the public interest.

¹⁴ *Id.* at para. 24

B. *Location-Determination-Enabled Devices Are Not a Solution.*

It has been noted that cognitive radios could incorporate the capability to determine their location and the location of other transmitters, through use of geolocation techniques such as those based on the global positioning system (GPS). Such radios could then access a database over a network, in order to select the appropriate transmission parameters, based on the location of the cognitive radio and other transmitters. While such capabilities do not have the flaws of DFS and frequency agility as applied to determination of passive observation, location determination coupled with database access does not appear to be a practical solution to the protection of passive users of the spectrum.

There are numerous problems with such an approach. For example, location determination would not solve interference problems created by cognitive radio transmission on EESS bands, since remote-sensing observations of the entire continental United States are continuously made. Information from data for the entire United States is used in numerous remote-sensing applications that are critical to maximizing environmental protection, as well as to the U.S. economy.

It is for all of the above reasons that CORF strongly believes that the Commission should continue to *prohibit unlicensed devices (including cognitive radios) from emitting on the restricted bands* set forth in Section 15.205 of the Commission's rules. See, Section 15.202 of the Commission's rules. This

prohibition is the only practical and effective way to protect passive users of the spectrum from harmful interference from these devices.

V. Responses to Other Questions in Paragraph 44 of the NOI.

The above sections of these Comments are intended to respond to a number of the questions posed by the Commission in paragraph 44 of the NOI. Responses to the remainder of the questions in that paragraph are as follows.

Should the Commission conduct a spectrum inventory?

CORF supports the proposal to conduct a spectrum inventory, as long as such an inventory is conducted in a manner that recognizes the “use” and “utilization” of the spectrum by passive scientific users of the RAS and EESS bands.

What is the most effective way to assess use of the spectrum—allocations, licenses, spectrum monitoring, user surveys?

CORF believes that, at the very least, reference to allocations must be included in the assessment of spectrum use, since none of the other methods listed would capture the passive scientific use of the spectrum.

CORF also believes that it would be effective for the Commission to engage in spectrum monitoring, and that the results of such monitoring should be made available to the public.

How should the Commission’s joint spectrum policy responsibilities with the National Telecommunications and Information Administration (NTIA) inform the inventory process?

CORF believes that in conducting any spectrum inventory, the Commission must be mindful of spectrum managed and assigned by NTIA, and

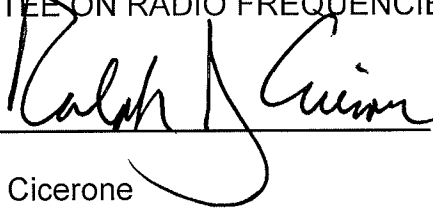
coordinate any inventory with NTIA, in order to ensure accurate and complete results.

VI. Conclusion.

CORF supports the proposal to conduct a spectrum inventory, as long as such an inventory is conducted in a manner that recognizes the “use” and “utilization” of the spectrum by passive scientific users of the RAS and EESS bands, as discussed above. Furthermore, the FCC should continue to protect those uses of the spectrum moving forward.

Respectfully submitted,

NATIONAL ACADEMY OF SCIENCES'
COMMITTEE ON RADIO FREQUENCIES

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