Before the
FEDERAL COMMUNICATIONS COMMISSION
Washington, D.C. 20554

In the Matter of)
)
Amendment of Parts 2, 15, and 97 of the)
Commission's Rules to Permit Use of)
ET Docket No. 94-124
Radio Frequencies Above 40 GHz for New)
Radio Applications)

COMMENTS OF THE NATIONAL ACADEMY OF SCIENCES' COMMITTEE ON RADIO FREQUENCIES

The National Academy of Sciences, through the National Research Council's Committee on Radio Frequencies (hereinafter, CORF), hereby submits its Comments in response to the Commission's Second Notice of Proposed Rulemaking, FCC 95-499, released December 15, 1995, in the above-captioned proceeding (Notice). In these Comments, CORF strongly supports establishing a level on spurious emissions in the 200-231 GHz band from millimeter-wave transmitters. CORF suggests that a limit of 2 pW/cm^2 at a distance of 3 m, measured over the 200-231 GHz band, be required. This limit is consistent with the standard below 200 GHz that has been adopted for 46 GHz vehicular radars and is necessary to provide protection to one of the most important radio astronomy bands, namely 217-231 GHz.

I. INTRODUCTION.

The Radio Astronomy Service makes extensive use of the millimeter-wave radio band. Molecules of substantial astrophysical importance produce narrow-band (spectral line) emission and absorption at specific frequencies that are determined by fundamental physical properties of the molecules. These spectral lines are used as probes of the physical conditions and dynamics in dense interstellar clouds and circumstellar envelopes. In addition to spectral line emission, continuum (broad-band) emission is observed at millimeter wavelengths from a variety of astrophysically important processes.

One of the most important millimeter-wave radio astronomy bands is 217-231 GHz. This band is allocated for exclusive use of passive services. Within this band fall several spectral lines arising from various isotopes of the carbon monoxide (CO) molecule. The emission and absorption of radiation by CO are important because they allow the determination of the distribution of molecular gas in the universe. Resonant frequencies of the CO spectral lines are 219.56, 220.40, and 230.54 GHz, but because of the Doppler effect, the lines are observed at a continuous range of frequencies throughout the 217-231 GHz band and outside of this band. Red-shifted CO lines have been observed well below 200 GHz. Other CO spectral lines are observed near 115 GHz, and the combination of data obtained in these two bands provides a powerful tool for astrophysical analysis.

Many other astrophysically important molecules are observed in the 217-231 GHz band. Surveys of the band have shown it to be particularly rich in both simple molecules and complex organic species. These molecules trace the evolution of cosmic material from an initially diffuse state to the dense condensations from which stars and planets form.

The 217-231 GHz band is also important for continuum observations of the cosmic background radiation, i.e., the weak, broad-band, and pervasive electromagnetic noise remaining from the origin of the universe (the Big Bang). The peak of this background radiation occurs near 160 GHz, and scientists use the relatively nearby 217-231 GHz passive allocation to observe the radiation's distribution. These observations ultimately are used to test theories of the origin of the cosmos.

Continuum observations of radiation from a variety of other sources, including dust and ionized gas clouds in interstellar space, are also made in the 217-231 GHz band. Extremely sensitive continuum observations in the band are proving to be a key to determining the particulate content of the very dense clouds from which stars form. These particles, in the form of icy dust grains, are probably the reservoir from which comets form and from which the atmospheres, oceans, and ice mantles of planets eventually arise.

U.S. millimeter-wave radio observatories are operated by federally funded agencies and by private (academic) institutions receiving government grants. The National Radio Astronomy Observatory (NRAO) is currently designing the Millimeter Wave Array (MMA), a major millimeter-wavelength interferometric observatory. These facilities constitute a considerable investment of U.S. government funds, which should be protected.

II. INTERFERENCE CALCULATIONS.

To analyze the potential interference from the third harmonic caused by 76-77 GHz vehicular radars to the Radio Astronomy Service at 217-231 GHz, the following characteristics of the radars were assumed: a frequency modulated signal, swept over 100 MHz in approximately 2 ms, with an instantaneous bandwidth of ~1 MHz and a 100% duty cycle. The harmful interference limits for the Radio Astronomy Service are set forth in ITU/CCIR Recommendation ITU-R RA.769 (1992). The harmful interference limit has been standardized as the received emission level that will produce a 10% increase in system noise fluctuations during an integration of 2000 s duration when received in the 0 dBi sidelobe of the telescope.

Existing radio astronomy observatories vary considerably with respect to the factors that affect their vulnerability to this form of interference. These factors include atmospheric transparency, distance from a public road, and level of traffic. For example, the California Institute of Technology's Owens Valley Radio Observatory is within sight of U.S. highway 395. The NRAO 12-m telescope is situated next to a public road leading to the popular visitor center at the top of Kitt Peak and is adjacent to a picnic area. The top of Mauna Kea, with several millimeter-wave telescopes, is protected from heavy tourist traffic only by an unpaved 8-km segment on the road to the summit. In our calculations, we therefore assumed an observatory situated in a good site at a distance of 0.25 km from a public road, with a visitor center or other public facility to attract traffic.

In the 217-231 GHz band, atmospheric absorption provides negligible protection at a good observatory site. Taking Mauna Kea (altitude 4.1 km) as an example, and assuming 1.0 mm of precipitable water typical of good but not exceptional atmospheric conditions, we computed an absorption of 3.8% per km at 217 GHz and 4.1% at 231 GHz. This is due almost entirely to absorption by water vapor, so that even for poor quality atmospheric conditions with 5 mm of precipitable water, the absorption is only about 20% per km. We therefore ignored atmospheric absorption in our calculations.

For continuum observations, ITU-R RA.769 defines a threshold interference level at 224 GHz of -114 dB(W/m^2), or 4 x 10^{-4} pW/cm^2, at the telescope. If the transmitter producing this flux density is 0.25 km away, then at the reference distance of 3 m from the transmitter the flux density would be 2.8 pW/cm^2.

For spectral line observations, ITU-R RA.769 defines a threshold interference level at 220 GHz of -133 dB(W/m^2), or 5 x 10^{-6} pW/cm^2, in a 2.5 MHz bandwidth. A transmitter 0.25 km away operating at this threshold flux density would have a flux density at 3 m of 3.5 x 10^{-2} pW/cm^{-2}. Assuming that the transmitter power is spread over 300 MHz (three times the 100 MHz sweep), then only 0.833% of the power falls within a spectrometer channel, and the total transmitter power could be 4 pW/cm^2.

The ITU Handbook on Radio Astronomy (Section 4.2.2) points out that "it has been the usual practice to use 2000 s as a representative averaging time. In recent years longer integration times have become more common and 36,000 s (10 h) could be taken as representative of high-sensitivity observations." A longer integration time increases the susceptibility to interference by 6.3 dB. Also, receiver sensitivity is improving dramatically and in some bands already approaches the fundamental noise limit imposed by photon statistics. The noise in a photon-statistics-limited receiver at 220 GHz would be dominated by thermal noise from the antenna, the ground as seen through sidelobes, and the atmosphere, and would be about 3 dB more sensitive than the typical receiver considered in ITU-R RA.769. In general, radio astronomical measurements at millimeter wavelengths routinely reach or exceed the sensitivity levels quoted in this document.

III. <u>EMISSION STANDARDS.</u>

A. <u>Proposed Power Density Limits.</u>

The Commission has adopted service rules to allow vehicular radar operation in the 46.7-46.9 and 76-77 GHz bands. The third harmonic of the 76-77 GHz band is 228-231 GHz, which falls entirely within the 217-231 GHz band exclusively allocated to radio astronomy. The Notice proposes a spurious-emission standard of S_{3m} = 1000 pW/cm^2 above 200 GHz. This proposed standard would cause severe harmful interference to radio astronomy facilities at 250 m (e.g., from nearby public roads and parking lots at observatories), and, by the inverse square law, the proposed level would require a single vehicular radar to be at a distance of nearly 5 km from the observatory in order to meet the harmful-interference limit. Most observatories are not able to regulate vehicular traffic in such a large surrounding area.

The Notice suggests applying spurious-emission standards to frequencies up to 231 GHz. Below 200 GHz, the Notice proposes spurious-emission standards of 600 pW/cm^2 for 76-77 GHz radars, but a substantially smaller value of 2 pW/cm^2 for 46.7-46.9 GHz radars (all power densities measured at 3 m distance). CORF proposes that a third-harmonic spurious-emission standard of 2 pW/cm^2 at a distance of 3 m, measured over the 228-231 GHz band, be required. This limit conforms to the standard below 200 GHz that has been adopted for 46 GHz vehicular radars. The proposed limit of 2 pW/cm^2 is approximately 75 dB below the 3 m power limit of 60 W/cm^2 at the fundamental frequency, a suppression level that radio astronomy millimeter-wave engineers believe can be achieved. Spurious-emission limits below 200 GHz adopted for 46 GHz vehicular radars are also 75 dB down from the fundamental.

The proposed 2 pW/cm^2 limit is a major improvement, but would not fully protect the most sensitive and, often, the scientifically most important observations. CORF believes that additional measures will be required in the future to protect millimeter-wavelength observatories.

B. Breadth of Application of Emission Limits.

The Notice asks whether limits on spurious emissions should be extended the entire 200-231 GHz band or limited to the 217-231 GHz band. The radio astronomy community believes that a 2 pW/cm^2 limit should apply at least to spurious emissions in the 217-231 GHz band. However, good engineering practices suggest application of a limit to spurious emissions between 200 and 217 GHz as well. As a result of the Doppler effect, spectral-line observations of many astrophysically significant molecules, including important observations of CO red-shifted lines, often must be made at frequencies below 217 GHz. With increasing use of millimeter-wave frequencies, the adoption of uniform spurious-emission standards would be beneficial to all spectrum users.

The Notice also asks whether emission limits above 200 GHz should be applied to all millimeter-wave transmitters or limited to vehicular-radar systems operating in the 76-77 GHz band. Spurious emissions from vehicular radar currently appear to constitute the greatest threat of harmful interference to radio astronomy observations in the 200-231 GHz band. Nevertheless, CORF remains concerned that many other millimeter-wave technologies could quickly be developed within the technical parameters established by the Commission, and these technologies could have sufficient ubiquity and power to seriously compromise radio astronomy observations throughout the nation. Accordingly, CORF believes that the safest and most administratively efficient approach is to apply spurious-emission standards to all millimeter-wave transmitters. If advocates of a particular technology can make a showing that there is no foreseeable harm to radio astronomy, then the Commission could grant a waiver of the spurious-emission standards in that case. Radio astronomers recognize the need to build alliances with users of other services and are prepared to be generous in support of technologies that do not generate harmful spurious emissions.

C. Probability of Interference by Vehicular Radar.

The Notice asks whether vehicular radar manufacturers could demonstrate such a low probability of interference that enactment of spurious-emission limits would be unnecessary. The Notice states, for example, that the angular distribution of vehicular-radar systems might be shown to substantially reduce interference. However, radio astronomers do not believe that specifying limits on beam widths for vehicular radars is a viable solution to the interference threat, since such limits will obviously apply only at the fundamental frequency of 76-77 GHz. Antenna-beam performance at the third harmonic will be difficult to predict. Furthermore, since radars will operate while vehicles are traveling uphill, downhill, and around curves, specifying beam-width limits does not keep the radar beams from illuminating off-road objects, such as a radio telescope.

Furthermore, in evaluating the impact of vehicular radar, the Commission must consider the volume of potential traffic. Section 4.2.4 of ITU R-RA.769 establishes a standard under which "no more than 10% of the initially averaged data (periods of tens of milliseconds to tens of seconds) should be lost when contaminated data is rejected." Under the Notice's proposed 600 pW/cm^2 standard, a vehicular radar transmitting from a distance of 0.25 km greatly exceeds the harmful level, and data contaminated by this interference must be rejected. The ITU's internationally recognized radio astronomy standard (already much more tolerant than that for other services) could tolerate no more than one car passing within a harmful distance approximately every 50 minutes. However, the traffic level is certainly higher, at least during the daytime, at the remotely located National Radio Astronomy Observatory at Kitt Peak and at the Berkeley-Illinois-Maryland Array at Hat Creek, California. While observatories are typically located outside urban areas, some more remote locations are close to major roads and are located in areas attractive to substantial numbers of tourists.

Finally, the need for maintenance of vehicular-radar units after their initial production, in order to retain compliance with spurious-emission limits, remains a major concern, and undercuts the ability of radar manufacturers to demonstrate that radio astronomical interference is unlikely. Since many automobiles are operated with improperly functioning headlights, tires, windshield wipers, seatbelts, and other safety items, it is reasonable to expect that many vehicles, because of minor collision damage or improper maintenance, will be operated with radar systems that do not meet the manufacturers' initial spurious-emission standards. While this is beyond the control of the radar manufacturers, it should be taken into account when specifying initial spurious-emission limits. Besides being an interference problem, an improperly functioning millimeter-wave radar system also may pose a health hazard. We urge that appropriate steps be taken to monitor statistically the actual performance of operating vehicular radars and that design changes be required for later models if mandated standards are not met.

IV. Conclusion.

The radio astronomy community is concerned about the potential impact of a likely proliferation of vehicular-radar systems. Considering that there are nearly 200 million registered motor vehicles in the United States, the potential for interference to radio astronomy observations from vehicular-radar spurious emissions is serious. Indeed, it could lead to a situation analogous to that experienced by many formerly important optical astronomy observatories whose activities are now severely curtailed as a result of light pollution from nearby cities.

While society is increasingly encountering constraints to growth caused by resource exhaustion and environmental contamination, the one area of growth that should be inexhaustible is the acquisition and utilization of new knowledge. Therefore, the sources of new knowledge, in this case a scientifically crucial part of the electromagnetic spectrum, must be protected from careless pollution. History has shown repeatedly that the sources of socially significant and economically important new knowledge cannot be predicted. Indeed, many of the great scientific discoveries that have transformed society and the economy have been serendipitous. For example, one of the most vigorous areas of chemistry todayfullerenes and carbon nanotubesoriginated in radio astronomical research into large interstellar molecules and grains. Accordingly, the segments of the electromagnetic spectrum set aside for radio astronomical research (including the band at 217-231 GHz) are invaluable and must be diligently protected.

Respectfully submitted,

NATIONAL ACADEMY OF SCIENCES'
COMMITTEE ON RADIO FREQUENCIES

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