Before the
FEDERAL COMMUNICATIONS COMMISSION
Washington, DC 20554

In the Matter of	)	
	)	
Reallocation of the 216–220 MHz,	)	WT Docket No. 02-08
1390–1395 MHz, 1427–1429 MHz,	)	RM-9267
1429–1432 MHz, 1432–1435 MHz,	)	RM-9692
1670–1675 MHz, and 2385–2390 MHz	)	RM-9797
Government Transfer Bands	)	RM-9854

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[1] (hereinafter, "CORF"), hereby submits its comments in response to the Commission's February 6, 2002, Notice of Proposed Rulemaking in the above-captioned docket ("NPRM"). In these comments, CORF makes recommendations designed to prevent or limit interference harmful to the research of the users of the Radio Astronomy Service ("RAS") and Earth Exploration Satellite Service ("EESS") who make observations in the 1.4 GHz and 1.6 GHz bands.

I. Introduction: The Importance of RAS and EESS Observations in the 1.4 GHz and 1.6 GHz Bands, and the Unique Vulnerability of Passive Services to Out-of-Band and Spurious Emissions.

CORF has a substantial interest in this proceeding, as CORF represents the interests of the scientific users of the radio spectrum, including users of the RAS and EESS making observations in the 1.4 GHz and 1.6 GHz bands. Both RAS and EESS observers perform extremely important yet vulnerable research.

As the Commission has long recognized, radio astronomy is a vitally important tool used by scientists to study our universe. Through the use of the RAS, scientists have in recent years made the first discovery of planets outside the solar system, circling a distant pulsar. Measurements of radio spectral-line emissions have identified and characterized the birth sites of stars in our own galaxy and the complex evolution and distribution of galaxies in the universe. Radio-astronomy measurements have discovered ripples in the cosmic microwave background, generated in the early universe, that later nucleated the formation of the stars and galaxies we know today. Observations of supernovas have witnessed the creation and distribution of heavy elements essential to the formation of planets like Earth and of life itself.

The EESS represents a unique resource for monitoring the global atmospheric and surface state of Earth and has made critical contributions to the study of land resource management, hazard prediction,

[1] A roster of the committee membership is attached.

meteorology, oceanology, atmospheric chemistry, and global change. Currently, instruments operating in the EESS bands provide regular and reliable quantitative atmospheric, oceanic, and land surface measurements to support a rich variety of scientific, commercial, and government (civil and military) data users. Applications of the data include aviation forecasts; flooding, hurricane, and severe storm warning and tracking; seasonal and interannual climate forecasts; decadal-scale monitoring of climate variability; medium-range weather forecasting; and studies of the ocean surface and internal structure, as well as many other applications.

Such current benefits of scientific research—based on observations in the 1.4 GHz and 1.6 GHz bands obtained through years of work and substantial federal investment—as well as future benefits, must be protected.

As passive users of the spectrum, radio astronomers and Earth scientists have no control over the frequencies at which they must observe, or over the character of the signal transmitted by natural phenomena. These parameters are set by the laws of nature. Furthermore, the emissions that radio astronomers receive are extremely weak—a typical radio telescope receives only about one-trillionth of a watt from even the strongest cosmic source and routinely receives signals from sources even one million times weaker than that. Because radio astronomy receivers are designed to pick up such remarkably weak signals, these facilities are particularly vulnerable to interference from spurious and out-of-band emissions from licensed and unlicensed users of neighboring bands and from those that produce harmonic emissions that fall into the RAS bands. The emissions received by passive EESS radiometers in Earth orbit are similarly weak: a hundredth-of-a-trillionth-of-a-watt change in emission can represent the difference between observing a land surface that is dry and absorbent and one with saturated soil and a propensity for runoff and flooding during extreme precipitation events. This sensitivity to interference is compounded by the fact that EESS sensors are pointed down toward Earth's surface and potential out-of-band radiators.

Of particular concern in this proceeding is protection of RAS and EESS observations in the 1.4 GHz and 1.6 GHz bands. Observations in the 1400–1427 MHz band are very important to both radio astronomers and Earth scientists. For RAS, the 21-centimeter line (1420.406 MHz) of neutral atomic hydrogen is perhaps the most frequently observed radio spectral line. Over 90 percent of the atoms in the universe are hydrogen, and most of those are in the atomic ground state. As a result, the discovery and regular observations of this spectral line have revolutionized humankind's understanding of the structure of our galaxy, and indeed, of the entire universe. Numerous detailed studies of the distribution of neutral hydrogen in our own and other galaxies are being used to investigate the state of interstellar matter, the dynamics and distribution of interstellar gas, the rotation of our own and other galaxies, and the potential for star formation in other galaxies, and to estimate the masses of galaxies.

Because of the Doppler effect,[2] the radiation of the 21-centimeter line is shifted from its rest frequency (1420 MHz) to lower frequencies. The amount of frequency shift (redshift) is an indicator of the distance to the emitting source, and accordingly, readings of such redshifts have provided distance measurements to more than 6,000 galaxies, contributing significantly to our understanding of the structure of galaxy distribution and thus of the history of the universe. Similarly, because of galactic rotation, some objects in our own galaxy appear to be moving away from, and others toward, Earth, resulting in shifting of the 21 centimeter line to higher or lower frequencies, respectively.

The 1400–1427 MHz band is also heavily used for radio astronomy continuum observations. Indeed, the *ITU Handbook on Radio Astronomy* (Geneva, 1995) lists the 1400–1427 MHz band as one of the preferred bands of the spectrum for continuum observations.[3]

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[2] Because the universe is expanding, more distant objects appear to be moving at increasingly higher velocities away from Earth.

[3] *Id.*, at Section 3.2, Table 1. The table is reproduced from Table 3 of Recommendation ITU-R RA.314.

The importance of protecting observations of redshifted hydrogen also extends to the 1390–1395 MHz band. These shifts to lower frequencies are the result of the large velocities at which distant galaxies are moving away from our galaxy. As noted in paragraph 20 of the NPRM, recognition of the importance of these observations is reflected in Footnote US311.

RAS research based on observations in the 1400–1427 MHz band has been one of the most fruitful areas of research in astronomy since the hydrogen line was first detected, and interest in the band continues unabated. In the United States alone, observations are conducted at the Green Bank, West Virginia, and Socorro, New Mexico sites of the National Radio Astronomy Observatory (NRAO); with the Very Long Baseline Array NRAO facility (10 RAS antennas distributed across the continental United States and in Hawaii and the Virgin Islands); and at the Arecibo, Puerto Rico, observatory of the National Astronomy and Ionosphere Center. The Allen Telescope Array at Hat Creek Radio Observatory will begin observations this year. A very large portion of RAS telescope time at these facilities is spent on observations in the 1400–1427 MHz band, and this high level of use is expected to continue.

The 1400–1427 MHz band—the primary band for EESS observations below 6 GHz—is essential for measurement of soil moisture and ocean salinity using spaceborne remote sensors. Spaceborne passive sensing provides the only means of measuring global soil moisture, and the 1400–1427 MHz band is the only band allocated for EESS that can be used for this application.

Soil moisture plays a key role in Earth's hydrological cycle by storing water and driving the exchange of water between Earth and the atmosphere. Furthermore, water in the top layer of soil drives global thermal cycles by changing the soil's thermal conductivity and heat capacity. Thus the ability to monitor soil moisture is critical for assessing the health of crops and gauging the extent and severity of drought and flooding. Such information is essential for disaster management, can help to ensure agricultural resilience, and contributes to military battlespace environment awareness.

The large international investment in soil moisture monitoring using the protected 1400–1427 MHz band is reflected in the extensive empirical database that has been assembled over the past 30 years to characterize the natural microwave emission responses of soil moisture, composition, and roughness, and agricultural and natural vegetation canopies. Several government agencies, most notably the U.S. Department of Agriculture, are engaged in extensive airborne campaigns to monitor soil moisture using this frequency band.

The 1400–1427 MHz band is also crucial for global measurement of ocean surface salinity, which plays a very important role in processes that influence global climate and ocean circulation, air-sea interaction, and the evaporation-precipitation balance. These processes drive both climate change and near-term weather cycles. Global observations of ocean surface salinity under nearly all weather conditions hold the promise of improving the accuracy of numerical weather models, which would yield significant safety and economic value to ocean-oriented industries and naval operations.

A similarly large international investment in ocean salinity monitoring using the protected 1400–1427 MHz band is reflected in the exhaustive laboratory and satellite studies of the ocean's dielectric properties conducted over the past several decades. Several government agencies, most notably the U.S. National Oceanic and Atmospheric Administration, are engaged in extensive airborne campaigns to measure ocean surface salinity in the 1400–1427 MHz frequency band.

For monitoring of both soil moisture and sea surface salinity, the response of the natural microwave emission to the physical quantities of interest diminishes rapidly above the 1400–1427 MHz band. This natural signal diminution above the band, combined with the increased likelihood of interference below the band and the extensive body of knowledge assembled from measurements in the band, make 1400–1427 MHz a unique and necessary frequency range for ongoing and future EESS observations.

The technology for achieving sufficient spatial resolution for passive spacebourne sensors operating in the 1400–1427 MHz band has only recently matured. Accordingly, several such sensors for measuring soil moisture and sea surface salinity are currently in the planning and development phases in both Europe and the United States. These include the Aquarius, Hydros, and SMOS (Soil Moisture and Ocean Salinity) missions. The most programmatically advanced of these missions is the SMOS, which uses a processing technique called aperture synthesis to achieve the required surface spatial resolution. Aperture synthesis combines measurements from more than one broad beam antenna to effectively synthesize a smaller beam. Currently the only viable means of achieving global coverage at the required surface spatial resolution, this technique is especially sensitive to interference because the offending radiation is received over a wide field of view. The requirements for measuring soil moisture to an accuracy of 4 percent volumetric moisture and salinity to 0.1 psu (practical salinity units) drive requirements for sensor radiometric accuracy to 0.2 Kelvin. Of this allowable error, approximately 10 percent, or 0.02 Kelvin, can be permitted from interference.

CORF is pleased that the NPRM recognizes the importance of protecting radio astronomy observations at 1660–1670 MHz (NPRM at paras. 107–113 and 123) and notes that there are exclusive primary and co-primary allocations to the RAS in the 1660–1660.5 MHz, 1660.5–1668.4 MHz, and 1668.4–1670 MHz bands. There is a reason for these primary allocations: observations in and around these frequency bands are among the most important for scientists studying stellar expansion velocities and theories of the origin and evolution of the universe. In addition, the *ITU Handbook on Radio Astronomy* lists the 1660–1670 MHz band as one of the preferred bands of the spectrum for continuum observations (*Id.*, at Section 3.2, Table 1) and includes observations of the hydroxyl radical at the rest frequencies of 1665.402 and 1667.359 MHz as being among those of greatest importance to radio astronomy (*Id.*, at Section 3.3, Table 2).

In sum, observations in the 1.4 GHz and 1.6 GHz bands at issue in this proceeding are critically important for continued unique RAS and EESS research, yet like all passive scientific observations are uniquely vulnerable to interference from out-of-band and spurious emissions. It is essential that licensees in adjacent and nearby bands be good neighbors and accept responsibility for preventing harmful interference to scientific observations.

II. Protection of Radio Astronomy Observations at 1.4 GHz and 1.6 GHz.

In paragraph 105 of the NPRM, the Commission seeks information on out-of-band interference limits in the 1.4 GHz and 1.6 GHz bands at issue in this proceeding. In addition, at paragraphs 107–110, the Commission seeks comments on three specific industry proposals for out-of-band emission limits designed to limit harmful interference from transmissions at 1670–1675 MHz into the protected RAS band at 1660.5–1668.4 MHz. Similarly, the NPRM notes at paragraph 123 that footnote US311 provides some protection to RAS observations at 1350–1400 MHz. Protection of radio astronomy observations is addressed below, while protection of Earth remote sensing is discussed separately in Section III of these comments.

CORF begins with the principle that the threshold levels of interference detrimental to the RAS in the 1400–1427 MHz and 1660–1670 MHz bands are given in Recommendation ITU-R RA.769, where the threshold values of spectral power flux density are –255 and –237 dBW/m^2/Hz, respectively, for the two bands. These values take into account the fact that the 1400–1427 MHz band is widely used for continuum observations, whereas the 1660–1670 MHz band is used mainly for spectral line observations. It is important to note that these limits apply to the signal *received* by the radio astronomy observatory, and not the signal *transmitted* by the licensee. Most U.S. radio astronomy sites are located within line of sight of a highway along which vehicles using the mobile services allocated in this proceeding may be expected to operate. For a line-of-sight distance of, for example, 10 km, the threshold levels given above correspond to values of effective isotropically radiated power (EIRP) of –164 and –146 dBW/Hz, which would be the approximate limits required for emission into the two respective RAS bands. Accordingly, CORF recommends that these threshold levels form the basis for Commission rules on out-of-band and emission limits or emission masks in the 1.4 and 1.6 GHz bands at issue in this proceeding.[4]

As an alternative to the use of out-of-band emission limits, protection of RAS observations in the 1.4 GHz and 1.6 GHz bands can be accomplished through the use of exclusion and coordination zones, as described below, for fixed and mobile services, respectively.

In regard to *fixed services*, CORF recommends the use of mandatory coordination procedures similar to those already enacted in Sections 1.924(a) and 1.924(d) of the Rules.[5] While protection of the NRAO Green Bank and Arecibo observatories could be accomplished merely by making the fixed licensees of the bands at issue in this proceeding whose out-of-band emissions will fall in the 1400–1427 MHz and 1660–1670 MHz bands explicitly subject to Sections 1.924(a) and 1.924(d), these sections do not currently provide protection for other important observatories. Accordingly, CORF recommends that the Commission enact a new provision (perhaps as a new part of Section 1.924) for coordination procedures for applications proposing fixed uses in the bands at issue in this proceeding within the zones described in footnote US311.[6]

In regard to *mobile services* using the frequency bands at issue in this proceeding, CORF recommends that the licenses issued for such services exclude areas nearby the observatories, since coordination with individual mobile handsets is not possible. For example, the Commission's rules could specify that all licenses issued will exclude the specified areas for each of the observatories listed in footnote US311. This licensing rule would also be consistent with the approach reflected in US311, which requires the Commission to make "every practicable effort to avoid the assignment of frequencies" to mobile services that could interfere with RAS observations at 1.4 GHz.

An approach based on footnote US311 would also be appropriate in addressing out-of-band emissions from fixed and mobile services in the 1390–1395 MHz band. In paragraph 123 of the NPRM, the Commission recognizes the importance to radio astronomy of the 1350–1400 MHz band, which includes the newly allocated 1390–1395 MHz band. As noted above, footnote US311 requires that the Commission "make every practicable effort" to avoid the assignment of frequencies in this band to fixed and mobile services that could interfere with radio astronomy observations at radio astronomy observatories specified in the footnote. CORF remains concerned about the potential harmful impact on radio astronomy observations at 1350–1400 MHz from ubiquitous land mobile transmissions at 1390–

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[4] CORF notes that these levels are more stringent than the levels discussed in paragraphs 107–110 of the NPRM and would require suppression of unwanted emissions in the RAS bands by more that 60 dB relative to the levels in the bands allocated to the transmitting service taking the example of AeroAstro in paragraph 108. Of the three industry proposals set forth in paragraphs 107-110, CORF considers the AeroAstro proposal for out-of-band limits to be the most protective of RAS observations, and certainly prefers it to the proposals of ArrayCom and MircroTrax (para. 109–110). CORF emphasizes that the protection levels stated in the main text of its comments above are appropriate for protection of RAS observations, especially in these critical bands. CORF notes further that for purposes of evaluating interference within a primary RAS band, radio astronomy should suffer no more than a 2 percent loss of data from interference from any one network (Recommendation ITU-R RA.1513).

[5] The requirement for fixed services to coordinate with RAS observatories should apply even if such services are licensed for large geographic areas, as opposed to being licensed on a site-by-site basis.

[6] Footnote US311 currently lists two observatories at the same location: Hat Creek Observatory and the Allen Telescope Array. (See the Commission's January 2, 2002, Reallocation Report and Order in this proceeding, FCC 01-382, at page 57.) In other filings, CORF and the National Science Foundation have recommended that these two listings be consolidated into one. While there has been some suggestion that the site should be designated as "Allen Telescope Array," upon reflection CORF believes that the listing should most appropriately be designated as "Hat Creek Radio Observatory, Hat Creek, California." The reason is that while the Allen Telescope Array is one of the instruments at this site, there are other instruments at the site as well. Furthermore, in all other cases, the footnotes name the site rather than the instrument at the site, and in this case the name of the site is the Hat Creek Radio Observatory.

1395 MHz. While land mobile transmissions occur at low elevation angles relative to the horizon, thus placing them outside the main antenna lobes of the radio telescopes, the intensity of their radiation will create significant interference when coupled into the radio telescope antennas via very weak (0 dBi) sidelobes. As discussed in Recommendation ITU-R RA.769, the flux density that creates significant interference to spectral line work when coupled into a 0 dBi sidelobe of a radio telescope operating at 1375 MHz is –240 dBW/m^2/Hz. Since a mobile unit operating in the 1350–1400 MHz band at the 20 watt EIRP power level specified in Part 27.50 of FCC Rules will create a flux density in excess of –170 dBW/m^2/Hz, even when located 10 km from the radio telescope, coordination between the mobile service and the radio observatory and protection of the RAS observations via power flux density limits are critical.

To limit the potentially harmful interference from mobile services in the 1350–1400 MHz band, CORF recommends that the Commission adjust the licensing areas of 1390–1395 MHz licenses to take into account nearby radio astronomy observatories. CORF recommends that the 1390–1395 MHz license areas explicitly exclude the geographic areas set forth in footnote US311. This recommended approach would be the best way to fulfill the requirements of footnote US311 in that it would be the most practicable way of avoiding assignment of frequencies in the 1350–1400 MHz band to mobile stations that could interfere with radio astronomy observations.

Although CORF is concerned primarily with interference from mobile transmitters in the 1350–1400 MHz band, fixed transmitters present significant concerns as well. While CORF does not suggest the exclusion of 1390–1395 MHz fixed transmitters from the geographic zones defined in footnote US311, it does recommend that the Commission's rules provide that such fixed facilities coordinate with affected radio astronomy facilities prior to filing applications, in a manner similar to that provided for in Sections 1.924(a) and 1.924(d).

III. Out-of-Band Emission Limits Necessary for the Protection of EESS Observations.

Protecting EESS observations is frequently more complicated than protecting RAS observations, because remote sensing systems image the entire United States and the adjacent oceans at approximately 80 km by 80 km resolution, measuring the total upwelling power from each 80 km by 80 km resolution cell. The natural surface emission signal is very small, and the accuracy to which it must be measured sets an upper limit for the total emission that can be allowed in the protected frequency band from the sum of all anthropogenic sources of emissions within the resolution cell. The calculations shown in Attachment A of this document demonstrate that the maximum total allowable emission into the 1400–1427 MHz band is –43 dBW (which is equivalent to 0.05 mW). Because this limit applies to the total upwelling power, calculations to determine levels for out-of-band suppression masks depend on assumptions made for (1) transmitter power at transmitter center frequency and (2) the total number of transmitters within the 80 km by 80 km (50 miles by 50 miles) resolution cell of the remote sensing system. Required mask suppression is calculated in Attachment A based on various sets of assumptions for transmitter power, ranging from 3 watts (mobile service) to 2,000 watts (fixed service), and for number of transmitters ranging from 10 to 50,000. A plot summarizing the results for the cases considered is included in Attachment A. Only a few illustrative examples are mentioned here.

Mobile transmitters emitting at 3 watts EIRP into the 1400–1427 MHz band would need to have a mask reducing transmissions by –78 dB if there were 1,000 transmitters in the resolution cell, but by –88 dB if there were 10,000 transmitters in the resolution cell. The requirements for reduced transmissions become more stringent if a service uses a higher transmission power. Considering the upper limit—a fixed transmitter operating at 2,000 watts EIRP—the service would have to reduce transmissions into the 1400–1427 MHz band by –86 dB below EIRP if there were 10 transmitters in the resolution cell, but by –106 dB if there were 1,000 transmitters in the resolution cell. These limits on out-of-band emission for protection of EESS measurements are consistent with ITU-R SA.1029-1, which fixes the limit of interference at –171 dBW within the band segment 1400–1427 MHz at the EESS receiver.[7]

IV. Conclusion.

Protection of the unique scientific observations made by RAS and EESS researchers using the 1.4 GHz and 1.6 GHz bands is critically important. CORF urges the Commission to adopt the recommendations herein as the most practical and effective means of ensuring such protection.

Respectfully submitted,

NATIONAL ACADEMY OF SCIENCES'
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[7] The above discussion considers only fairly simple cases, i.e., only one type of transmitter within the resolution cell. However, if a resolution cell contains some combination of high-power and low-power transmitters, the numbers of such transmitters and their respective masks would have to be designed such that the sum of all transmissions would remain below the allowable limit. CORF recognizes that drafting effective out-of-band emission limits will be a complex effort and expresses its willingness to work with the Commission and other parties to accomplish this task.

ATTACHMENT A

To avoid harmful interference within an EESS satellite footprint requires

$$P_{Tav} < 4\pi \frac{kT_{th}B}{\lambda^2 C},$$

where k = Boltzmann constant (1.38 x 10^{-23})
T_{th} = allowable interference threshold
B = bandwidth
λ = wavelength
C = coupling between transmit antenna and remote sensing antenna
P_{Tav} = average radiated power density (W/m^2).

The center frequency of the remote sensing receiver is 1413.5 MHz, which means that the wavelength, λ, is 21 cm. The allowable interference threshold, which is driven by the measurement sensitivity requirements for the remote sensing measurement, is 0.02 K. The coupling factor is determined by the path of the interfering signal (direct antenna to antenna versus multiple reflections). This value can range from –6 dB to –30 dB, or in linear terms, from 0.25 to 0.001. Accordingly, in the antenna-to-antenna case, the result is

$$P_{Tav} < 4\pi \frac{(1.38\times10^{-23})(0.02)(25\times10^{6})}{(0.21)^2(0.25)}.$$

The allowable power density, P_{Tav}, must be less than 7.865 x 10^{-9} W/km^2. Now, assuming a resolution cell of 80 km by 80 km, the total allowable power would be

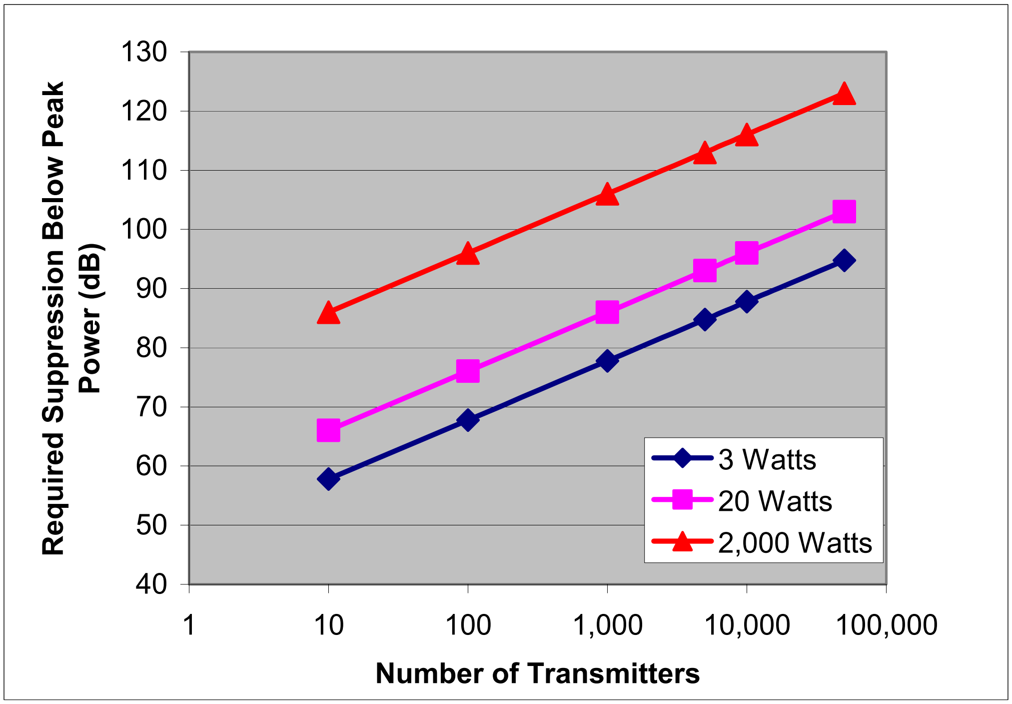
Max power = (7.865 x 10^{-9} W/km^2)(6400 km^2) = 0.05 mW.

To calculate the out-of-band suppression required by an individual transmitter, take

(Transmitter Power)(Suppression in Protected Band)(Number of transmitters) < 0.05 mW.

The plot below shows a family of curves for three different transmitter power levels, 3 W, 20 W, and 2,000 W. Required suppression for each transmitter is shown as a function of the number of transmitters within the resolution cell. The same data are also presented in tabular form. Similar calculations could be made for various combinations of transmitter types and number.

Note: derivation of the formulas used in the calculation above can be found in "Impacts of Mobile Radar and Telecommunications Systems on Earth Remote Sensing in the 22–27 GHz Range," Technical Assessment of the IEEE GRSS Technical Committee on Frequency Allocations in Remote Sensing (FARS), by A.J. Gasiewski, W. Wiesbeck, and C. Ruf, 2002.



Required Suppression (dB)

Number of Transmitters	3 Watts	20 Watts	2000 Watts
10	–57.78	–66.02	–86.02
100	–67.78	–76.02	–96.02
1,000	–77.78	–86.02	–106.02
5,000	–84.77	–93.01	–113.01
10,000	–87.78	–96.02	–116.02
50,000	–94.77	–103.01	–123.01
100,000	–97.78	–106.02	–126.02
1,000,000	–107.78	–116.02	–136.02

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COMMITTEE ON RADIO FREQUENCIES

Terms expire at the end of the month and year indicated.
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