Before the
FEDERAL COMMUNICATIONS COMMISSION
Washington, DC 20554

In the Matter of	)	
	)	
Establishment of an Interference Temperature	)	
Metric to Quantify and Manage Interference	)	ET Docket No. 03-237
and to Expand Available Unlicensed	)	
Operation in Certain Fixed, Mobile and	)	
Satellite Frequency Bands	)	

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[1]), hereby submits its comments in response to the Notice of Inquiry and Notice of Proposed Rule Making (NPRM), released November 28, 2003, in the above-captioned docket, seeking comments on a new "interference temperature" metric for quantifying and managing interference. Herein, CORF supports the Commission's general intent of quantifying and managing interference in a more precise fashion. However, in light of the tremendously weak signals observed by passive scientific users of the spectrum, and the long integration times used to make such observations, the use of the interference temperature metric cannot as a practical matter provide the protection needed for scientific observation. Accordingly, CORF strongly recommends that an interference temperature metric not be used in bands allocated for passive scientific observation, such as bands allocated to the Radio Astronomy Service (RAS) or to the Earth Exploration Satellite Service (EESS).

I. Introduction: The Importance of Radio Astronomy and Remote Sensing of the Earth, and the Unique Vulnerability of Passive Services to Interference

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

[1] A roster of the committee is attached.

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. Measurements of radio spectral line emission have identified and characterized the birth sites of stars in our own galaxy, and the complex distribution and evolution of galaxies in the universe. Radio astronomy measurements have discovered ripples in the cosmic microwave background, generated in the early universe, which later formed the stars and galaxies we know today. Observations of supernovas have allowed us to witness the creation and distribution of heavy elements essential to the formation of planets like Earth, and of life itself.

The EESS is a critical and unique resource for monitoring Earth's global atmospheric and surface state. Satellite-based microwave remote sensing represents the only practical method of obtaining uniform-quality atmospheric and surface data encompassing the most remote oceans as well as densely populated areas of Earth. EESS data have contributed substantially to the study of meteorology, atmospheric chemistry, oceanography, and global change. Currently, instruments operating in the EESS bands provide regular and reliable quantitative atmospheric, oceanic, and land measurements to support an extensive variety of scientific, commercial, and government (civil and military) data users. Applications of the data include aviation forecasts, hurricane and severe storm warning and tracking, seasonal and interannual climate forecasts, decadal-scale monitoring of climate variability, medium-range forecasting, and studies of the ocean surface and internal structure, as well as many others.

The emissions that radio astronomers study are extremely weak--a typical radio telescope receives only about *one-trillionth of a watt* from even the strongest cosmic source. Because radio astronomy receivers are designed to pick up such remarkably weak signals, such facilities are therefore particularly vulnerable to interference from spurious and out-of-band emissions from licensed and unlicensed users of neighboring bands, and those that produce harmonic emissions that fall into the RAS bands. Similarly, the emissions received by passive EESS radiometers in Earth orbit are weak by comparison with emissions from other services.

In addition to the gains in scientific knowledge that result from radio astronomy and Earth sensing, CORF notes that such research enables technological developments that are of direct and tangible benefit to the public. For example, radio astronomy techniques have contributed significantly to major advances in the following areas:

--<u>Computerized tomography</u> (CAT scans) as well as other technologies for studying and creating images of tissue inside the human body;

--Abilities to <u>forecast earthquakes</u> by very-long-baseline interferometric (VLBI) measurements of fault motions; and

--Use of VLBI techniques in the development of <u>wireless telephone geographic location technologies</u>, which can be used in connection with the Commission's "E911" requirements.

Continued development of new critical technologies enabled by passive scientific observation of the spectrum depends on scientists having continued access to interference-free spectrum. More directly, the underlying science undertaken by RAS and EESS observers cannot be performed without access to interference-free spectrum. Loss of such access constitutes a loss for the scientific and cultural heritage of all people, as well as for the practical civil and military applications arising from the information learned and the technologies developed.

II. General Discussion with Respect to the Radio Astronomy Service

As understood by CORF, the interference temperature metric would be a single-valued measure of the total noise-plus-interference environment. It would vary from one frequency band to another and possibly with time, but would not include information on the variation in interference level with respect to direction of incidence. The proposed new spectrum management technique based on interference temperature incorporates a more direct approach to some aspects of the problems of interference. This approach includes focusing primary attention on the level of interference at the victim receiver rather than relying on regulation of the transmitters, and it recognizes that the interference level can result from the combined effects of a number of transmitters. In principle this more detailed attention to the radio frequency environment could lead to more efficient protection of the spectrum. The concept of a single-valued metric to characterize the interference level fits nicely with use of the measured power received in an isotropic antenna. The response of such an antenna is a concept that has long been used by the RAS to calculate interference levels in large radio astronomy antennas, as in Recommendation ITU-R RA769. Unfortunately, in the case of the RAS, the measurement of interference temperature does not provide a practicable way to provide protection from interference.

A basic premise of the interference temperature concept is that comparable power levels of interference and noise result in comparable degradation to the operation of the service under consideration. This is a reasonable assumption for many communication systems. In the case of the RAS, however, interference at a given power level creates much greater degradation than does random noise of the same power level. To detect the small increase in noise power that occurs when the main beam of a radio astronomy antenna is pointed at a radio source, it is necessary to average the receiver output voltage over time intervals ranging from minutes to hours to reduce the noise fluctuations. The statistics of Gaussian random noise are very well understood, and the effect of averaging is to reduce the rms noise fluctuations by a factor equal to the square root of the product of receiver bandwidth (Hz) with averaging time (seconds). Receiver bandwidths used in the RAS vary from a few MHz to a few GHz; e.g., in the 1.4-GHz RAS band the receiver bandwidth is approximately 20 MHz. Averaging times can extend up to several hours, but for computations of sensitivity the RAS standard is 2000 seconds. With these figures the noise fluctuations are reduced by a factor of 2×10^5. Thus, after time averaging, the rms level of the noise temperature fluctuations is only 1/200,000 of the mean temperature level resulting from background noise. The reduction factor is larger for higher-frequency bands for which the bandwidth can be as high as 4 GHz.

For interfering signals, the effect of time averaging depends on both the type of modulation and the information being transmitted, and in general cannot be predicted. The power levels of interfering signals generally show relatively slow fluctuations due to variations in propagation loss, as well as occasional large changes due to the transmitters switching on and off. Further, even if the temperature of an interfering signal remains constant at the radio astronomy antenna, the power received through the sidelobes will vary as the antenna tracks the sidereal motion of the astronomical source under observation.[2] This is in contrast to the noise power (temperature) in a receiving system that is relatively stable with time. Thus the interference will introduce low-frequency components at the output of the radio astronomy receiver, of amplitude comparable to the mean power (temperature) level of the interference. The time averaging will have little effect in reducing such slow variations, so for interference and noise of equal power in the radio astronomy receiver, the interference will cause fluctuations on the order of 10^5 greater than the rms noise fluctuations. This problem is peculiar to radio astronomy and passive sensing since, in general, other services do not include long time averaging of the signal at the output of the detector.[3] Furthermore, unlike true noise, it is possible for interference to be mistaken for an astronomical source.

For the RAS, the threshold levels of interference, based on a response that is 10 % of the rms noise fluctuations after 2000-second averaging, are given in ITU Recommendation RA769. For example, for the 1400-1427 MHz band the threshold is -255 $dBWm^{-2}Hz^{-1}$, or 3.16×10^{-26} $Wm^{-2}Hz^{-1}$. The collecting area of an isotropic antenna[4] at this frequency is 3.5×10^{-3} square meters, so the equivalent interference temperature, which is equal to the power level received in an isotropic antenna divided by Boltzmann's constant, is $(3.16 \times 10^{-26}) \times (3.5 \times 10^{-3})/1.38 \times 10^{-23} = 8.0 \times 10^{-6}$ K. Values for some other bands are provided in Table 1. This value is the upper limit on variations in antenna temperature that can be allowed without degradation of the accuracy of the measurement of power received by a radio astronomy antenna.[5] Because the slow variations in the received power level of interfering signals are not appreciably reduced by time averaging, this value must be considered to represent the maximum tolerable interference level. It is clearly impractical to monitor such small temperature values for control of interference to the RAS.

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[2] During a 2000-second integration period, the tracking motion amounts to 4.2° for, say, a source declination of 60°. The angular width of a sidelobe, e.g., for a 25-m-diameter antenna at 1.4 GHz, would be about 1°. Thus several deep, slow fluctuations in the received interference power would occur during the averaging period.

[3] It may be argued that in the case of signals from a very large population of low-power transmitters, the random scatter of amplitudes and phases would cause the interference to average down more effectively. However, in such a case, it is likely that the interference would be dominated by one or two nearby transmitters.

[4] The collecting area of an isotropic radiator is equal to the square of the wavelength divided by 4π.

[5] Several techniques are used to maintain sufficient instrument stability to measure such small power levels. These include rapid switching of the receiver input between the antenna and a reference load, rapid switching of the pointing angle of the main beam of the antenna, or correlation of signals from spaced antennas (i.e., interferometry).

Table 1. Examples of Detrimental Interference Temperatures for the RAS

Frequency (MHz)	**Detrimental Interference Level ($dB(Wm^{-2}Hz^{-1})$)**	**Interference Temperature (K)**
608-614	–253	7.0×10^{-5}
1400-1427	–255	8.0×10^{-6}
4990-5000	–241	1.7×10^{-5}
42,500-43,500	–227	5.6×10^{-6}

The problem of the weakness of signals from cosmic radio sources, compared with communication signals, can be illustrated by noting that approximately 2 million discrete sources have been individually measured and catalogued from measurements near 1.4 GHz, but their average flux density is so small that their combined effect increases the noise power in an isotropic antenna by only 0.1 K. Thus their contribution to the noise background for communications purposes is negligible. From their measured positions we know that these sources are mostly associated with radio galaxies and quasars far beyond the limits of our Milky Way Galaxy. Observations of the most distant (and correspondingly weakest) sources are important for investigation of questions of basic physics such as the nature of dark matter.

With regard to actions that could be taken to prevent the interference temperature from exceeding a specified limit, ¶13 of the NPRM suggests that "[a]nother approach would be to change the direction or shape of the transmit antenna pattern." If this statement applies to unlicensed devices, it is not clear how this approach would work since the proposed regulation is based on a metric that contains no information on the variation of the interference temperature with direction.

III. General Discussion with Respect to the EESS

Below, CORF summarizes the proposed use of interference temperature as a primary metric for frequency use evaluation in the case of the EESS, and then provides a quantitative illustration of how the use of interference temperature has corrupted EESS measurements. As shown below, the interference temperature metric is not useful in protecting EESS observations.

In ITU-R SA.1029, the standard for the level of interference harmful to EESS observations is approximately 10^{-3} K. While that level is higher than the level established for the RAS, the region of EESS use is global--urban, rural, and over sea. Satellite-based receivers look at Earth's surface and therefore have mean noise temperatures of the absolute temperature of the surface, about 300 K. The "signal" in EESS observations consists of small changes in this mean level that are detectable, as in the RAS, by a combination of wide bandwidths and long integration times. ITU-R SA.1029 also states that this established interference level cannot be exceeded for more than 1 percent of the sensor's measurement cells either by in-band or by out-of-band emissions. Unlike the RAS case where a few transmitters near a site might be an issue, the EESS must deal with all transmitters over large areas. An example of the interference limit for the EESS is

–166 dBW in a 200-MHz bandwidth at 24 GHz, or –249 dB(W Hz^{-1}). The antenna etendue, which is the product of effective area and beam solid angle (wavelength^2 in the diffraction limit), is used to convert this limit to interference temperature.

Table 2. Examples of Detrimental Interference Temperatures for the EESS

Frequency (GHz)	Detrimental Interference Level (dB(W Hz^{-1}))	Interference Temperature (K)
1.400-1.427	–254	1 x 10^{-3}
10.6-10.7	–243	16 x 10^{-3}
24.0	–249	4 x 10^{-3}

The problems that use of the interference temperature metric would pose for the EESS by can be illustrated by describing the EESS radiometers currently in orbit and observing in the 6-GHz region. NASA's Advanced Microwave Scanning Radiometer for EOS (AMSR-E) measures vertically and horizontally polarized brightness temperatures at 6.925 GHz, and the U.S. Naval Research Laboratory's WindSat radiometer also measures vertically and horizontally polarized brightness temperatures at 6.8 GHz. Both sensors operate from low Earth orbit in sun-synchronous orbits. Measurements at 6 GHz are used to support retrieval of soil moisture measurements over land, and over oceans to retrieve data on sea surface temperature and sea surface winds. Loss of such data means loss of significant research capability relevant to understanding the health and evolution of our planet.

According to the emitter databases, the 6.525 -- 7.125 GHz region primarily contains fixed service (FS) transmitters. The typical FS transmitter in this region has a ~50-dB antenna pointed at the horizon ~150 feet above ground level with ~1 to 2 W delivered to the antenna. Typically, EESS radiometers operating in this band are impacted by FS transmitters when the radiometers receive emissions from the transmitting antenna's sidelobes into the main lobe of the radiometer's antenna. The extent of this interference over North America is quite significant. An example from the AMSR-E sensor is shown in Figure 1.

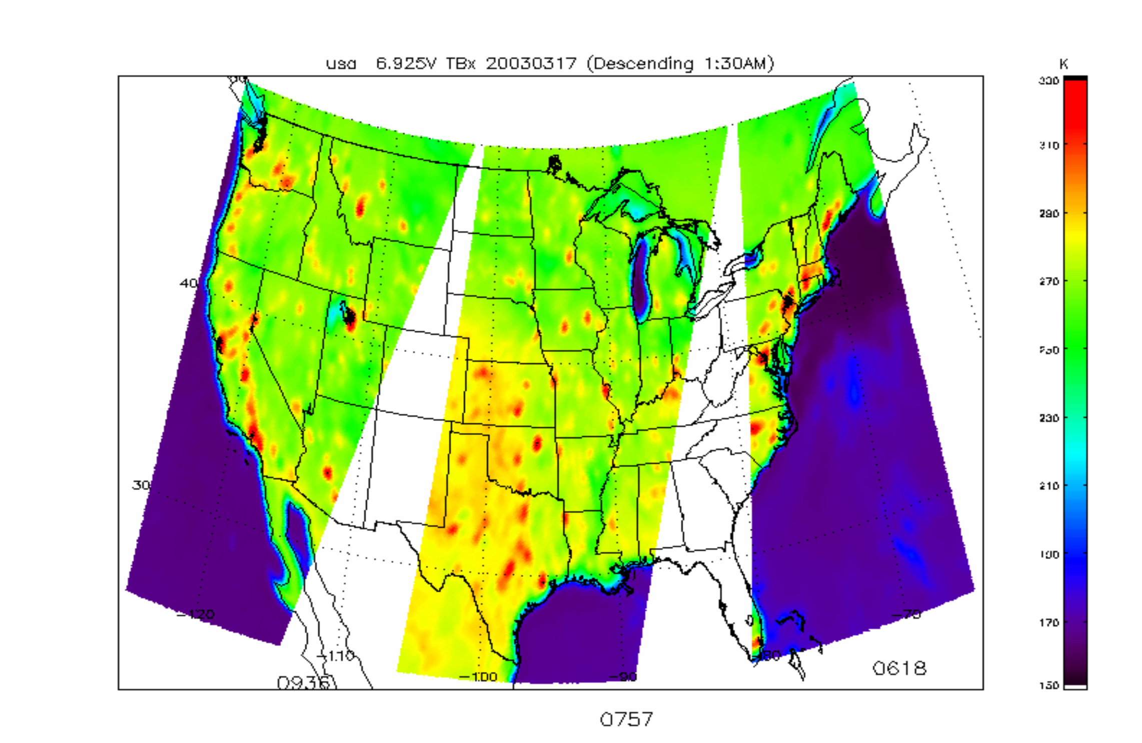

Figure 1. An example of anthropogenic interference over North America, March 17, 2003.

The red spots (gray splotches in black and white displays) indicate regions of anthropogenic emission. Retrieval of environmental parameters can be adversely affected when interference is received in excess of a fraction of the sensitivity of the radiometer. For measurements of soil moisture, the interference threshold is variable, but generally less than 1 K is cause for the data to be rejected. This level of interference appears to affect roughly 50 % of land area of the United States.

EESS's metrics for evaluation of detrimental interference could be expressed directly as interference temperature. However, the precision of the temperature level required to measure physical effects at Earth's surface is so far below the ambient temperature level that the proposed interference temperature metric will not be useful in protecting EESS observations.

IV. Replies to Questions

¶20 (iii): Should the introduction of interference temperature devices be done in stages to ensure that the incumbent services do not suffer undue interference?
¶20 (iv): If the introduction were to be done in stages how should we limit the initial introduction of interference temperature devices to protect the incumbent systems?

CORF notes that it would be very difficult to withdraw permission for use of unlicensed devices if the interference temperature concept proved to be unsuccessful in preventing harmful interference to established services. Thus, CORF strongly recommends that any introduction of regulation based on the interference temperature metric should be done in stages, to allow time for careful examination of the results. As a test of the system, the initial introduction could be restricted to a limited geographic area.[6]

¶21 (vii): In bands where several services share the spectrum on a primary or secondary basis, should the interference temperature limit be based on all the licensed services or only on the service most susceptible to interference? How would this be determined? Is the I+N of a primary service meaningful to a secondary service?

In bands shared by several services, CORF believes very strongly that the interference temperature limits should be chosen to protect all incumbent users, not just the primary services.

¶21 (xiv): Are there some services or bands for which the Commission should continue to use the current interference protection procedures?

As shown above, it is not practicable to measure the very low values of interference temperature that would be necessary to protect the RAS. A more practical approach to protection of radio astronomy observations is to estimate power levels of interfering signals from characteristics of the transmitters and propagation losses, as is the current procedure. Thus, in response to the question, CORF strongly recommends that in bands allocated to the RAS and the EESS the Commission should continue to use current interference protection procedures. CORF also believes very strongly that unlicensed devices should not be used in bands with primary allocations to radio astronomy and passive sensing.

¶26: We request comments on how to define the noise floor?

For the RAS the noise floor is defined solely by natural noise sources (cold sky, atmospheric noise, ground radiation (if any), and receiver noise). Radio telescopes are built at remote sites to minimize any additional man-made noise. This advantage should not be negated by the introduction of interference-temperature-based spectrum management. CORF also emphasizes that the RAS has a threshold for detrimental interference that is typically some 53 dB *below* the conventional noise floor of its low-noise receiver systems (see discussion in section II of this document).

[6] The establishment of the National Radio Quiet Zone (NRQZ) is intended to facilitate radio astronomy observations at Green Bank, West Virginia, over a wider range of spectrum than is available within the bands specifically allocated to radio astronomy. CORF therefore strongly recommends that, to preserve the present radio-quiet environment, the interference temperature metric should not be used in the NRQZ. Similarly, Section 1.924(d) provides for coordination, with the Arecibo Observatory, of applications in many licensed services in Puerto Rico. For similar reasons, the interference temperature metric should not be used in Puerto Rico until it is demonstrated in practice that use of such a metric does not lead to harmful interference to RAS observations.

¶28 (i): For a given service in a given frequency band how much interference can be tolerated before it is considered harmful?

With respect to this question, the levels of interference that can be tolerated by radio astronomy are those listed as detrimental thresholds in Recommendation ITU-R RA.769. Percentages of time for which these thresholds can be exceeded are specified in Recommendation ITU-R RA.1513. The corresponding remote sensing standard is ITU-R SA.1029.

¶28 (ii): Can interference from a transmitter be distinguished from naturally occurring noise?

After time averaging of the received signals in a radio astronomy receiver, it is generally not possible to distinguish between the random variations resulting from the noise and those due to variations in received interference power. Thus weak interference, which is not easily identified in the presence of noise, is generally considered to present the greatest danger of producing false results. Before time averaging is applied, noise and interference are often readily distinguishable if the interference is strong compared with the noise.

¶38: *Use of ΔT/T Limit for FSS Operations in the 6525-6700 MHz and 12.75-13.25 GHz Bands.*

The Commission suggests the use of EIRP emission levels as high as 4 W for unlicensed devices. CORF understands that currently a typical EIRP limit on emissions of unlicensed devices would be 500 mV/m at a distance of 3 m (Section 15.145 of the Commission's rules), which corresponds to an EIRP of 75 mW. Thus 4 W would be an increase in EIRP of a factor of 53, or 17 dB. CORF views such a large increase in EIRP with some concern and recommends that a careful check be made of the effect of such power levels on other services within the same band.

¶48: We request comments on whether any portion of the bands discussed above that are allocated for fixed operation should be excluded from consideration under this proposal and why. For example, is it necessary to preclude unlicensed operation in the 6650-6675.2 MHz portion of this band to protect radio astronomy operations or can suitable technical standards be developed to ensure that harmful interference is not caused?

In response to the questions on protection of radio astronomy operations, CORF believes that it is clearly necessary to preclude unlicensed operation and use of the interference temperature metric in the 6650-6675.2 MHz portion of the 6526-6700 MHz band. That band is used for observations of the 6668.5 MHz methanol line, which is listed in Recommendation ITU-R RA.314, among the lines of the greatest importance to radio astronomy, as well as in RR 5.149.

¶*49: Out-of-band Emissions.*

The interference threshold level for spectral line observations in the 6525-6700 MHz band is –228 $dBW^{-2}Hz^{-1}$ (interpolated from Table 2 of Recommendation ITU-R RA.769). For free space transmission, an EIRP of –27 dBm/MHz (–87dBm/Hz) produces a spectral power flux density equal to this interference threshold at a distance of 100 km. At a free space distance of 1 km, a signal at the interference threshold would be produced by an EIRP of –67 dBm/MHz.

V. Summary

As discussed above, due to the extreme weakness of the signals observed by passive scientific users of the spectrum, and the long integration times used to make such observations, the use of the interference temperature metric cannot as a practical matter provide the protection needed for scientific observation. Accordingly, CORF strongly recommends that the interference temperature metric not be used in bands allocated for passive scientific observation, such as bands allocated to the RAS and the EESS, nor in geographic areas such as the NRQZ or the Puerto Rico Coordination Zone. Initial implementation of the interference temperature metric should not be done bands allocated for passive sensing.

Respectfully submitted,

NATIONAL ACADEMY OF SCIENCES'
COMMITTEE ON RADIO FREQUENCIES

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