APPENDIX A

ASSESSMENT OF PROPOSED POWER LEVEL AND DETECTION THRESHOLD IN THE 6 GHz AND 13 GHz FIXED SERVICE FREQUENCY BANDS

INTRODUCTION

This appendix assesses the feasibility of the Commission's proposal for sharing between higher-powered unlicensed devices and fixed service (FS) systems in the 6 GHz and 13 GHz bands. The analysis considers an unlicensed device operating at an equivalent isotropically radiated power level (EIRP) of 36 dBm located 100 meters from the FS receiver.[1] The unlicensed device employs Dynamic Frequency Selection (DFS) and has a detection threshold of -64 dBm.[2] The DFS detection threshold of –64 dBm is based on technical studies assessing compatibility between 5 GHz radar systems and Unlicensed National Information Infrastructure (U-NII) devices.[3] The FS transmitter power received at the unlicensed device is computed based on typical parameters for the FS link and compared to the proposed detection threshold. The transmitted signal from the unlicensed transmitter at the FS receiver is computed and compared to the interference-to-noise (I/N) threshold of –13 dB, which corresponds to a 5 percent increase in system noise in the receiver.[4]

1. *Establishment of an Interference Temperature Metric to Quantify and Manage Interference and to Expand Available Unlicensed Operation in Certain Fixed, Mobile and Satellite Frequency Bands*, Notice of Inquiry and Notice of Proposed Rulemaking, ET Docket No. 03-237, 18 F.C.C. Rcd. 25309, at ¶ 47 (2003).

2. *Id.*

3. *Revision of Parts 2 and 15 of the Commission's Rules to Permit Unlicensed National Information Infrastructure (U-NII) Devices in the 5-GHz Band*, Report and Order, ET Docket No. 03-122, 18 F.C.C. Rcd. 24484 (2003).

4. ITU-R Recommendation F.1094 permits a 1 percent increase in system noise attributable to non-primary (unlicensed) interference sources, which corresponds to an I/N = -20 dB.

FS SYSTEM PARAMETERS

The parameters for the FS systems considered in this assessment are given in Table A-1.

Table A-1.

Parameter	Value	
	6 GHz	13 GHz
Frequency	6600 MHz	13000 MHz
Transmitter Power	30 dBm	30 dBm
Mainbeam Antenna Gain	44 dBi	44 dBi
Line Loss	2 dB	2 dB
Antenna Height	50 m	50 m
Transmitter/Receiver Bandwidth	40 MHz	40 MHz
Noise Figure	4 dB	4 dB
Path Length	40 km	20 km
Antenna Mask	32-25 Log(Off-Axis Angle)	32-25 Log(Off-Axis Angle)
Minimum Carrier-to-Noise Ratio	28 dB	28 dB

UNLICENSED DEVICE PARAMETERS

The parameters for the unlicensed device considered in this analysis are provided in Table A-2.

Table A-2.

Parameter	Value
EIRP	36 dBm
Antenna Gain	0 dBi
Antenna Height	2 m
Transmitter Bandwidth	20 MHz
DFS Detection Bandwidth[5]	1 MHz

5. The Commission's proposal did not include a measurement bandwidth for the detection threshold. A bandwidth of 1 MHz is used consistent with the value used in the U-NII DFS device and radar analysis that determined the –64 dBm threshold.

ASSESSMENT OF PROPOSED DFS DETECTION THRESHOLD

The level of the FS transmitted signal received by the unlicensed device is computed using the following equation:

$$P_U = P_{FS} + G_{FS} - L_T - L_P - L_{Clutter} - BWCF + G_U \quad \text{(A-1)}$$

where:

P_U is the FS transmitted power received by the unlicensed device (dBm);
P_{FS} is the transmitted power of the FS (dBm);
G_{FS} is the mainbeam antenna gain of the FS (dBi);
L_T is the insertion loss for the FS transmitter (dB);
L_P is the propagation loss (dB);
$L_{Clutter}$ is the clutter loss (dB);
BWCF is the loss due to the difference between the FS transmit and detection measurement bandwidths (dB);
G_U is the antenna gain of the unlicensed device (dBi).

In this assessment, the Irregular Terrain Model (ITM) is used to compute the propagation loss.[6] The parameters used in the ITM propagation model are shown in Table A-3.

Table A-3.

Parameter	Value
Frequency	6600 MHz, 13000 MHz
Polarization	Vertical
FS Transmitter Site Criteria	Careful
Unlicensed Device Receiver Site Criteria	Random
Delta H	10 meters
Dielectric Constant	15
Surface Refractivity	301 N-Units
Conductivity	0.005 S/m
Radio Climate	Continental Temperate
Percent Time	10%
Percent Location	50%
Confidence Level	50%
Mode of Variability	Mobile

6. National Telecommunications and Information Administration, Institute for Telecommunication Sciences, NTIA Report 82-100, *A Guide to the Use of the ITS Irregular Terrain Model in the Area Prediction Mode* (April 1982).

In the development of the -64 dBm detection threshold, the 5 GHz studies included a clutter factor that was randomly varied between 0 dB and 20 dB. In this assessment, a value of 13 dB is used for the clutter factor.

The level of the received signal from the FS transmitter will be reduced due to the mismatch in bandwidth between the FS transmitter of 40 MHz and the detection bandwidth of 1 MHz used in this assessment. The bandwidth correction factor is given by:

$$BWCF = 10 \text{ Log } (1/40) = -16 \text{ dB}$$

Using Equation A-1, the power level of the received FS transmitted signal at the unlicensed device is shown in Table A-4 for the 6 GHz and 13 GHz links.

Table A-4.

Parameter	Value	
	6 GHz	**13 GHz**
P_{FS}	30 dBm	30 dBm
G_{FS}	44 dBi	44 dBi
L_T	-2 dB	-2 dB
L_P	-153 dB	-138 dB
$L_{Clutter}$	-13 dB	-13 dB
BWCF	-16 dB	-16 dB
G_U	0 dBi	0 dBi
P_U	-110 dBm	-95 dBm

As shown in Table A-4, the computed FS transmitted signal power levels received by the unlicensed device are well below the proposed detection threshold of -64 dBm. Since the received FS transmitted power levels are below the detection threshold, a DFS equipped unlicensed device would sense that the channel is not being used and would be permitted to transmit.

ASSSESSMENT OF INTERFERNCE TO FS RECEIVERS FROM UNLICENSED DEVICES OPERATING AT THE PROPOSED POWER LEVEL

The power level of the unlicensed device transmitter at the FS receiver is computed using the following equation:

$$P_R = EIRP_U - L_R - L_{FS} - L_{Clutter} - BWCF + G_{FS} \qquad \text{(A-2)}$$

where:

P_R is the unlicensed device transmitted power received by the FS receiver (dBm);
$EIRP_U$ is the EIRP of the unlicensed device (dBm);
L_R is the insertion loss for the FS receiver (dB);
L_P is the propagation loss (dB);
$L_{Clutter}$ is the clutter loss (dB);
BWCF is the loss due to the difference between the FS receiver and the unlicensed device bandwidths (dB);
G_{FS} is the gain of the FS receive antenna in the direction of the unlicensed device (dBi).

Since the unlicensed device is assumed to be operating 100 meters horizontally from the FS receiver, the free space propagation model given by the following equation applies:[7]

$$L_P = 20 \text{ Log } F + 20 \text{ Log } D - 27.55 \qquad \text{(A-3)}$$

where

L_P is the free space propagation loss (dB);
F is the frequency (MHz);
D is the distance separation between the unlicensed device and the FS receiver (m).

Since there is a difference between the antenna heights of the unlicensed device and the FS receiver the slant range is used to compute the separation distance. The slant range is computed as follows:

$$D = (100^2 + (50-2)^2)^{1/2} = 111 \text{ meters}$$

Since the separation distance is only 111 meters it is not appropriate to include a clutter factor.

The 40 MHz bandwidth of the FS receiver is larger than the 20 MHz unlicensed device transmitter bandwidth so the bandwidth correction factor is 0 dB.

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7. For separation distances of less than 1 kilometer, the ITM propagation model defaults to the free space model.

The FS receive antenna gain in the direction of the unlicensed device is a function of the off-axis angle which is computed as follows:

$$\text{Off-Axis Angle} = \text{Tan}^{-1}((50-2)/100) = 25.6 \text{ degrees}$$

Using the antenna gain mask from Table A-1, the FS receive antenna gain in the direction of the unlicensed device is:

$$G_{FS} = 32 - 25 \text{ Log } (25.6) = -3.2 \text{ dBi}$$

Using Equation A-2, the power levels received at the FS receiver from the unlicensed device transmitter are shown in Table A-5.

Table A-5.

Parameter	**Value**	
	6 GHz	**13 GHz**
$EIRP_U$	36 dBm	36 dBm
L_T	-2 dB	-2 dB
L_P	-89.7 dB	-95.6 dB
$L_{Clutter}$	0 dB	0 dB
BWCF	0 dB	0 dB
G_{FS}	-3.2 dBi	-3.2 dBi
P_R	-58.9 dBm	-64.8 dBm

The noise power of the FS receiver is computed using the following equation:

$$N = -114 + 10 \text{ Log } (RBW) + NF \qquad \text{(A-4)}$$

Where:

N is the receiver noise power (dBm);
RBW is the receiver bandwidth (MHz);
NF is the receiver noise figure (dB).

Using the values of FS receiver bandwidth of 40 MHz and noise figure of 4 dB, the FS receiver noise power is -94 dBm.

The I/N is the difference between the power level of the unlicensed device transmitter at the FS receiver and the receiver noise power:

$$I/N = -58.9 - (-94) = 35.1 \text{ dB} \qquad \text{(6 GHz)}$$

$$I/N = -64.8 - (-94) = 29.2 \text{ dB} \qquad \text{(13 GHz)}$$

The computed I/N values exceed the -13 dB threshold by 48 dB (6 GHz) and 42 dB (13 GHz). In order to reduce the interference received from the unlicensed device transmitter to meet the interference threshold of -107 dBm (-94 dBm - 13 dB), either the EIRP level of the unlicensed device must be reduced or the separation distance between the unlicensed device and FS receiver must be increased.

The maximum allowable EIRP levels referenced to a 1 MHz bandwidth that the unlicensed device can have and still meet the interference threshold are:

$$36 - 48 + 10 \text{ Log } (1/40) = -28 \text{ dBm/MHz} \qquad (6 \text{ GHz})$$

$$36 - 29.2 + 10 \text{ Log } (1/40) = -9.2 \text{ dBm/MHz} \qquad (13 \text{ GHz})$$

These EIRP levels are below the proposal made by the Commission, but they are still higher than the general emission EIRP limit of -41.3 dBm/MHz currently permitted in this band under Part 15 of the Commission Rules.

If the unlicensed device has an EIRP level of 36 dBm, the separation distances from the FS receiver must be increased from 100 meters to 28 kilometers (6 GHz) and 14 kilometers (13 GHz).

In addition to an I/N, the carrier-to-interference (C/I) can also be used to assess potential interference to the FS receiver. The minimum carrier power level can be computed as follows:

$$C_{min} = C/N + N = 28 + (-94) = -66 \text{ dBm} \qquad \text{(A-5)}$$

The nominal carrier power at the FS receiver is computed using the following equation:

$$C_{nom} = P_{FS} + G_{FS} - L_T - L_P - L_T + G_{FS} \qquad \text{(A-6)}$$

where:

C_{nom} is the nominal carrier power level at the FS receiver (dBm);
P_{FS} is the transmitted power of the FS (dBm);
G_{FS} is the mainbeam gain of the FS transmit antenna (dBi);
L_T is the insertion loss of the FS transmitter (dB);
L_P is the propagation loss (dB);
G_{FS} is the mainbeam gain of the FS receive antenna (dBi).

To compute the nominal carrier levels the parameters from Table A-1 and the ITM propagation model are used. The nominal carrier power levels and the available fade margins for the link considered in this assessment are shown in Table A-6.

Table A-6.

Parameter	Value	
	6 GHz	**13 GHz**
P_{FS}	30 dBm	30 dBm
G_{FS}	44 dBi	44 dBi
L_T	-4 dB	-4 dB
L_P	-140 dB	-137 dB
G_{FS}	44 dBi	44 dBi
C_{nom}	-26 dBm	-23 dBm
C_{min}	-66 dBm	-66 dBm
Fade Margin	40 dB	43 dB

As shown in Table A-6, the fade margins for the links considered in this analysis are not excessive.

The minimum carrier power computed using Equation A-5 and the interference power levels given in Table A-5 can be used to compute the available C/I ratio using the following equation:

$$C/I = C_{min} - P_{FS} = -66 - (-58.9) = -7.1 \text{ dB}$$

$$C/I = C_{min} - P_{FS} = -66 - (-64.8) = -1.2 \text{ dB}$$

These computed C/I values are much lower than the values necessary to provide reliable performance on any FS link.

CONCLUSION

The combination of DFS detection threshold and EIRP level proposed for unlicensed devices operating in the 6 and 13 GHz frequency bands are not adequate to protect FS receivers from potential interference.

APPENDIX B

ASSESSMENT OF POTENTIAL INTERFERENCE TO GOLDSTONE DEEP SPACE NETWORK OPERATIONS IN THE 12.75-13.25 GHz BAND

INTRODUCTION

This appendix assesses the potential interference from unlicensed devices operating at the maximum equivalent isotropically radiated power (EIRP) level of 36 dBm as proposed by the Commission to Deep Space Network (DSN) receivers in the 12.75-13.25 GHz frequency band.

INTERFERENCE CRITERIA

The interference criteria used in this analysis to assess whether the unlicensed device causes interference to the DSN receiver is based on ITU-R Recommendation SA.1157.[1] In the 12.75-13.25 GHz band, a maximum allowable power spectral density of -220.5 dBW/Hz is specified. This interference criterion for the deep-space receiver is specified at the receiver input terminals.

ASSESSMENT OF INTERFERENCE TO DSN RECEIVERS

In this assessment, the distance separation required to preclude potential interference is computed based on the maximum EIRP level of 36 dBm proposed by the Commission and interference criteria specified in ITU-R Recommendation SA.1157.

The Commission's proposal does not specify a bandwidth for the unlicensed device. Unlicensed device bandwidths of 1 MHz and 20 MHz are used to compute the EIRP density used in this analysis.

$$EIRP_U = 36 \text{ dBm/MHz} - 60 - 30 = -54 \text{ dBW/Hz} \qquad (1 \text{ MHz})$$

$$EIRP_U = 36 \text{ dBm/20 MHz} - 73 - 30 = -67 \text{ dBW/Hz} \qquad (20 \text{ MHz})$$

The required propagation loss to preclude potential interference is calculated using the following equation:

$$L_P = EIRP_U - I_T \qquad \text{(B-1)}$$

where:

L_P is the required propagation loss necessary to preclude potential interference to the DSN receiver (dB);
I_T is the DSN receiver interference criteria (dBW/Hz);

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1. ITU-R Recommendation SA.1157, *Protection Criteria for Deep-Space Research* (1995).

$EIRP_U$ is the EIRP density of the unlicensed device (dBW/Hz).

Using Equation B-1 the values of required propagation loss are:

$L_P = 166.5$ dB (1 MHz)

$L_P = 153.5$ dB (20 MHz)

Using the required propagation loss, the Irregular Terrain Model (ITM) propagation model is used to determine the separation distance necessary to preclude potential interference to DSN receivers.[2] The parameters used in the ITM propagation model are given in Table B-1.

Table B-1.

Parameter	Value
Frequency	13000 MHz
Polarization	Vertical
Unlicensed Device Antenna Height	2 meters
DSN Receiver Antenna Height	10 meters
Unlicensed Device Transmitter Site Criteria	Random
DSN Receiver Site Criteria	Careful
Delta H	100 meters
Dielectric Constant	15
Surface Refractivity	280 N-Units
Conductivity	0.005 S/m
Radio Climate	Desert
Percent Time	10%
Percent Location	50%
Confidence Level	50%
Mode of Variability	Mobile

Based on the ITM propagation model, the following approximate separation distances are necessary to preclude potential interference to the DSN receivers:

$D_{Req} = 16$ km (1 MHz)

$D_{Req} = 8$ km (20 MHz)

Since the nearest populated town is approximately 72 km away, the computed approximate separation distances are small enough where an unlicensed device would have to be operated by Department of Defense (DoD) or National Aeronautics and Space Administration

2. National Telecommunications and Information Administration, Institute for Telecommunication Sciences, NTIA Report 82-100, *A Guide to the Use of the ITS Irregular Terrain Model in the Area Prediction Mode* (April 1982).

(NASA) personnel at the Goldstone complex to result in potential interference to DSN receivers.

Protection of the Goldstone radio frequency spectrum is essential for safeguarding data communication capabilities between spacecraft and the Goldstone tracking antennas. This spectrum protection is being successfully accomplished through mutual coordination between DoD and NASA. It is believed that this coordination and the existing spectrum monitoring activities will ensure that the DSN receivers are protected from unlicensed devices operating on the Goldstone facility.

APPENDIX C

DISCUSSION OF THE CRITICAL PARAMETERS OF THE INTERFERENCE TEMPERATURE MEASUREMENT SYSTEM

INTRODUCTION

This appendix discusses the different parameters that define the interference temperature measurement system. In general the interference temperature measurement system should be a spectrum analyzer (SA) based system that is computer controlled. A specialized front-end should be implemented before the SA that includes an effective bandpass filter and a low noise preamplifier. The low noise preamplifier is used to increase the dynamic range of the measurement system and the bandpass filter is used to protect the low noise preamplifier from being saturated by strong signals outside the passband. The critical parameters of the interference temperature measurement system include detector function, measurement bandwidth, noise figure, sensitivity, measurement time, and the measurement antenna. Statistical measurements of the signal environment are also discussed.

DETECTOR FUNCTION

Interference temperature measurements should be made using both peak and average detector functions. The peak detector function is used to measure the peak power level of a signal in a specified measurement interval. The average detector is a little more complicated, since "average" is a mathematically defined quantity, and many different averaging functions exist. These include, but are not limited to, linear average, logarithmic average, and root-mean-square (RMS) average.[1] The different average detector functions tend to emphasize particular parts of the time waveform that is being measured. The logarithmic detector function gives greatest weight to the relatively lower values in the time waveform and thus discounts voltage peaks or spikes. The linear average detector tends to be more affected equally by the whole range of signal values. The RMS detector function is related to the "voltage-squared" values of the time waveform, and as such tends to be more affected by the highest signal levels of the waveform. However, this voltage-squared aspect is a measurement of the true average power of the signal. A study performed by NTIA's Institute for Telecommunication Sciences (ITS) examined the effect of using different detector functions on measuring noise-like, pulse-like, and continuous wave signals.[2] The ITS study generally concluded that the divergence in measured values for the various average detector functions are different for the three average detector functions, but they would be even greater for signals that contain spikes, such as out-of-band emissions from low-duty cycle pulsed or impulse signals. The study also concluded that the

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1. The RMS detector determines the average power based on the RMS voltage levels that are measured.

2. National Telecommunications and Information Administration, Institute for Telecommunication Sciences, NTIA Report 01-383, *The Temporal and Spectral Characteristics of Ultrawideband Signals* (January 2001).

RMS detector gave the most accurate measure of the average power.[3]

Another type of averaging, often referred to as "video averaging" is performed by using a relatively wide resolution bandwidth (typically about 1 MHz) and a narrow video bandwidth (as narrow as a few hertz). The idea behind this technique is to utilize a resolution bandwidth that is sufficiently wide to follow fluctuations of the signal in the pre-detection stages, and then to obtain an average value by smoothing the measured signal with a narrow post-detection low pass filter (the video bandwidth). In effect, this average suppresses the broadband content of the measured signal, allowing measurement of its narrowband, continuous-wave component, if any exists. To illustrate the potential problem with using the video averaging technique, measurements of emissions from microwave oven measured using video averaging indicated levels which were tens of decibels lower than the value that would have been indicated by wide bandwidth, peak detected measurements.[4]

MEASUREMENT BANDWIDTH

In the SA based measurement system, there are two bandwidths of concern: the resolution bandwidth (RBW) also referred to as the IF bandwidth and the video bandwidth (VBW) which is referred to as the post-detection bandwidth. To perform interference temperature measurements that are representative of the signal levels that a licensed receiver would experience, the measurements should be performed in a bandwidth that matches the licensed receiver IF bandwidth. This may be difficult since most SAs have a limited set of fixed RBWs.[5] When the IF bandwidth of the licensed receiver does not match the available SA RBW, the RBW that is closest to matching the licensed receiver bandwidth should be employed. For example, if the licensed receiver has a IF bandwidth of 25 kHz it is appropriate to perform the interference temperature measurement using a RBW of 30 kHz. Performing the interference temperature measurement in a much wider RBW will reduce the sensitivity of the measurement.[6] If narrower RBWs are employed it will take longer to measure across a given frequency range and time delays in the reported interference temperature measurements will exist. If there are multiple radio services operating in a frequency band or if adaptive bandwidth technology is employed it may be necessary to perform the interference temperature measurements in several RBWs. The VBW employed in the interference temperature measurement should be as wide or wider than the RBW.[7] If the VBW is narrower than the RBW, the problems associated with the video averaging technique discussed earlier could be encountered.

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3. *Id.* at 8-13.

4. National Telecommunications and Information Administration, NTIA Report 94-303-1, *Radio Spectrum Measurements of Individual Microwave Ovens Volume I,* at 9 (March 1994).

5. SA RBWs may be selected from 0.01 to 3000 kHz, in a 1,3,10 progression. Modern SAs have RBWs as wide as 8 MHz.

6. Wider RBWs have higher noise levels which reduces the signal-to-noise ratio and the achievable sensitivity.

7. The rule-of-thumb is that the VBW should be three times wider than then RBW.

NOISE FIGURE AND SENSITIVITY

The preamplifier used in the front-end of the SA based interference temperature measurement system establishes the measurement system's noise figure, sensitivity, and dynamic range.[8] Since the noise figure of a SA is typically high (on the order of 20 to 30 dB), the overall noise figure of the measurement system is dominated by the noise figure of the first stage, which in this case is the preamplifier placed in front of the SA. By reducing the preamplifier's noise figure and or increasing its gain the sensitivity of the measurement system will improve. In an optimized measurement system, the sum of the preamplifier gain and noise figure should be nearly equal to the noise figure of the SA across the frequency range to be measured.[9] As with the bandwidth, the noise figure of the measurement system used to perform the interference temperature measurement should be representative of that used by the licensed receivers operating in the frequency band being monitored.

MEASUREMENT TIME

The measurement time includes both measurement interval on a specific frequency in a band and the time required to measure all of the frequencies in a segment of the spectrum. There are two approaches that can be used to measure the interference temperature across a band of frequencies: stepped frequency measurements and swept frequency measurements. In the stepped frequency approach the measurement consists of a series of individual measurements made at predetermined (fixed tuned) frequencies across a spectrum band of interest. The measurement system remains tuned to each frequency for a specified measurement interval referred to as the time step or dwell. The frequency interval for each step is typically set equal to the RBW of the measurement system. For each specified time interval the highest signal level occurring in that interval would be reported as the peak and the RMS is calculated based on the samples that occur during that interval. In the swept frequency approach the measurement system sweeps across the spectrum in individual segments that are referred to as spans. The frequency range of each span is then broken into individual frequency bins.[10] As the SA sweeps across a selected span, it spends a finite amount of time measuring the received power in each of the bins.[11] Within each measurement bin a single peak power level or RMS level is reported. The stepped frequency approach is typically used to capture peak signals occurring on an

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8. The dynamic range is the difference, in dB, between the maximum and minimum acceptable signal level in a measurement system.

9. A higher noise figure results in loss of sensitivity; gain that is too low will fail to overdrive the measurement system noise, while gain that is too high will reduce the available dynamic range of the measurement system. The desirable gain of the preamplifier can be estimated as follows: $G_{PA} = NF + L + 5$ dB; where NF is the noise figure in dB of the SA and L is the loss in dB in the cable connecting the preamplifier to the SA.

10. The number of bins is dependent on the SA. For example, Hewlett Packard SAs have 1001 frequency bins, whereas Agilent SAs have 601 bins.

11. For example, a 20 millisecond sweep time divided by 1001 measurement bins per sweep yields a 20 microsecond measurement time in each frequency bin.

intermittent basis, such as a periodically scanning radar. The swept frequency measurement approach can be used to measure the peak and RMS levels in highly dynamic frequency bands, such as the land mobile bands.

The measurement interval to be used in either the stepped or swept frequency approach is difficult to estimate without prior knowledge of the signal environment that is being monitored or the receivers that are to be protected. If the measurement interval is too short then reported values may not be accurate representations of the peak and RMS levels and the receiver may not be adequately protected. On the other hand, if the measurement interval is too long it will increase the time required to monitor a frequency band, introducing time delays in the reported interference temperature measurement levels. It may be possible to estimate the measurement interval based on the characteristics of the licensed signals. For example, if the licensed signal employs digital modulation with symbol or bit durations of 20 milliseconds, a measurement interval on the order of 20 milliseconds should be adequate to measure the RMS level and have a level that accurately represents the interference potential to that receiver. However, in general it will be necessary to perform preliminary measurements in a frequency band in order to determine the appropriate measurement interval to be employed.

MEASUREMENT ANTENNA

The antenna used to measure the interference temperature levels should have a gain pattern (e.g., omni-directional or directional) that is consistent with the antennas employed by the licensed user operating in the frequency band being monitored. Omni-directional, slant polarized, biconical antennas provide a good response to circular, vertical, and horizontal polarizations and are commercially available in the 0.1 to 20 GHz frequency range. A slanted-polarized log periodic antenna may also be employed if most of the radio activity is confined to an area subtending 180 degrees or less, relative to the measurement system. A variety of broadband cavity-backed spiral antennas have gain patterns that are most useful for directional measurements and are commercially available in the 1 to 18 GHz frequency range. Parabolic reflector antennas with a choice of feeds (linear, cross-polarized, and circular) are also an option for performing directional measurements.

STATISTICAL MEASUREMENTS

Receiver noise, which is stationary and Gaussian, can be characterized by one statistic, the mean temperature, and how it affects receiver performance, thus it is easy to define a noise temperature. For non-Gaussian noise such as impulsive processes, the mean temperature is not sufficient to adequately characterize the noise process and how it will affect receiver performance. In a study performed by ITS, using a simple matched filter receiver and Binary Phase Shift Keying modulation, it was found that receiver performance can be more severely degraded by non-Gaussian impulsive noise when compared to Gaussian noise, given the same mean temperature for both noise sources.[12] This result emphasizes that mean interference

12. National Telecommunications and Information Administration, Institute for Telecommunication Sciences, NTIA Report 82-95, *Digital System Performance Software Utilizing Noise Measurement Data* (February 1982).

temperature may not be sufficient to characterize the interference process and its effects on a particular receiver.

In addition to the peak and RMS measurements discussed earlier, amplitude probability distribution (APD) measurements should also be considered to characterize the signal environment.[13] APD measurements represent first order statistics that have proven to be a valuable technique used to characterize white Gaussian noise processes.[14] Interference from man-made noise processes are often more complex than white Gaussian noise processes, and may also require the use of higher order statistics for complete characterization to understand their effect on victim receivers.[15] Measurements made with the peak and RMS detector functions represent two points on the APD curve. This would require use of a spectrum analyzer capable of sampling the time waveform of the received signal(s), and possibly other more specialized equipment.

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13. APDs show the percentage of time that measured emissions exceed a given power threshold.

14. First order statistics accurately characterize variables that are independent and identically distributed.

15. Second order statistics measure the correlation between random variables.

APPENDIX D

DISCUSSION OF OPPORTUNITIES THAT CAN EXIST FOR UNLICENSED DEVICE USE IN CERTAIN AREAS, WHILE PROTECTING THE LOCATIONS THAT ARE POTENTIALLY MORE SENSITIVE TO INTERFERENCE

INTRODUCTION

This appendix provides an alternative to the method of implementing the interference temperature model as proposed by the Federal Communications Commission in the Notice of Inquiry (NOI) portion of the interference temperature rulemaking.[1] The alternative method is based on real-time measurement of desired (i.e. licensed) signal levels, and baseline measurements of noise levels existent in the frequency bands of interest. Existence (or lack thereof) of a desired signal at some level above the measured noise floor can be used as an indication of spectrum utilization. Licensed signal strengths that are well in excess of maximum noise levels (high signal-to-noise ratio (S/N)) could allow opportunistic use by unlicensed devices with a lower probability of causing harmful interference to licensed users. However, the high licensed signal level could present a challenge for the operation of the unlicensed service (i.e. operations in the presence of a high interfering signal level). Non-existence of a desired signal above the noise floor indicates that the spectrum is not currently being used in the location of the measurement. Therefore no harmful interference could occur and opportunistic use could be permitted. The geographic area in between these two extremes, however, is the area where receivers are most vulnerable to interference because the S/N is approaching the minimum usable value.

GENERIC COMMUNICATIONS SYSTEM STRUCTURE

Figure D-1 shows a block diagram that is typical of any radiocommunications link. This diagram is generic in that it does not show characteristics that are specific to a particular service, such as antenna type or pattern, antenna heights, and distance.

1. *Establishment of an Interference Temperature Metric to Quantify and Manage Interference and to Expand Available Unlicensed Operation in Certain Fixed, Mobile and Satellite Frequency Bands*, Notice of Inquiry and Notice of Proposed Rulemaking, ET Docket No. 03-237, 18 F.C.C. Rcd. 25309 (2003).

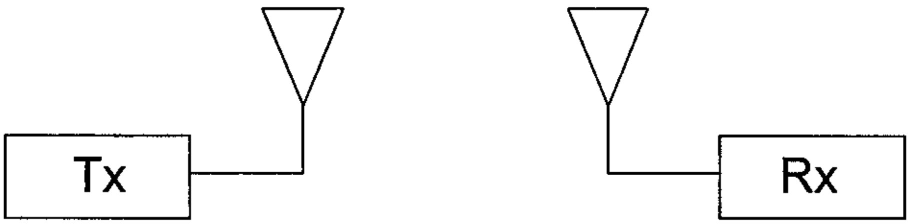

Figure D-1. Generic Communications Link Block Diagram

The generic equation that can be used to analyze the communications link in Figure D-1 is shown in Equation D-1 below:

$$P_R = P_T + G_T - L_P + G_R + G_{OTHER} \qquad \text{(D-1)}$$

Where: P_R is the usable power at the receiver;
P_T is the transmitter output power;
G_T is the transmit antenna gain in the direction of the receiver;
L_P is propagation losses (including terrain, vegetation, buildings, etc.);
G_R is the receive antenna gain in the direction of the transmitter;
G_{OTHER} is the gains or losses unique to the design of the system, such as processing gain or fading losses.

The S/N in the receiver is then determined by comparing the usable received power level (P_R) to the level of system noise (N). System noise is made up of thermal noise, as well as any undesired signal present in the receiver.

The bottom line in determining if a communication link is viable is determined by the S/N level within the receiver. Licensees must optimize the link equation to enable the particular type of service they wish to provide. That is, there must be sufficient S/N to use the received signal. Tradeoffs must be considered when optimizing the link equation to provide adequate service within acceptable costs.

P_T: Increasing P_T results in a corresponding increase in P_R. The tradeoffs are greater cost, reducing frequency re-use, increasing radiation hazards, reducing battery life, and increasing equipment size.

G_T: Increasing G_T results in a corresponding increase in P_R. The tradeoffs are greater cost, reduced gain in other directions, since increasing gain in one direction must result in decreasing gain in other directions (this could also be a benefit, depending on the type of service, since there would be more isolation toward off-axis receivers), and the physical size of directional antennas is typically larger than that of omni-directional antennas.

L_P: Decreasing L_P results in a corresponding increase in P_R. This can be accomplished by increasing the antenna height (e.g. on a tower), reducing the amount of obstructions in the path (e.g., use an outside antenna), or by reducing the distance between the transmitter and receiver.

G_R: Increasing G_R results in a corresponding increase in P_R. The tradeoffs are greater cost, reduced gain in other directions, since increasing gain in one direction must result in decreasing gain in other directions (this could also be a benefit, depending on the type of service, since there would be more isolation from off-axis interference), and the physical size of directional antennas is typically larger than that of omni-directional antennas.

G_{OTHER}: Increasing G_{OTHER} results in a corresponding increase in P_R. Increasing other system gains, such as processing gains, can allow reception of signals that are not usable without this gain. The tradeoffs are greater cost, and greater complexity of systems employing these gain factors.

ALTERNATIVE METHOD FOR IMPLEMENTING THE INTERFERENCE TEMPERATURE MODEL

Because licensees have built their systems to operate in the level of noise currently present and provide service to customers within a certain coverage contour, any increase in noise will likely require compensation by an increase in one of the factors in the link equation or else system performance will be degraded. However, in areas where excess margin exists, or where insufficient signal exists for a usable communications link, opportunities for unlicensed use could more easily be exploited. This can be seen in Figure D-2.

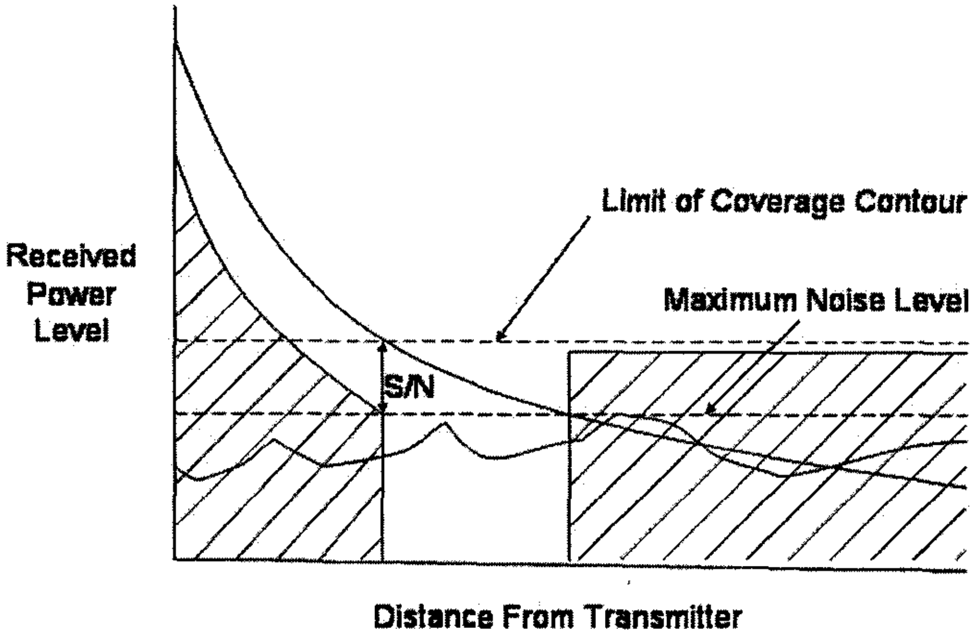

Figure D-2. Opportunities for Spectrum Access in Areas With Excess Margin or Lacking Sufficient Signal-to-Noise (S/N) for Licensed Service.

As shown in Figure D-2, opportunities can exist for unlicensed use in certain areas, while protecting the locations that are potentially more sensitive to interference. These areas of opportunity (the shaded areas in Figure D-2) could be utilized by unlicensed devices that are capable of measuring the radio frequency (RF) environment, and making a determination to transmit based on whether excess margin or insufficient desired signal exist, or a determination to not transmit if the desired signal level is such that an increase in noise could potentially disrupt communications.

MEASUREMENT CHALLENGES

Interference temperature is proposed within the NOI to be defined as a measure of the RF power generated by undesired emitters plus noise sources that is present in a receiver system (I+N) per unit of bandwidth.[2] Difficulty in measuring this quantity arises for several reasons.

2. *Id.* at ¶ 10.

First, the desired signal of the licensed service will be received along with any undesired signals. Hardware and/or software algorithms may be developed that are able to distinguish between a licensed desired signal and noise. Such a measurement process, however, would be very dependent on a detailed knowledge of the licensed signal. Requirement of such an in-depth knowledge of licensed signal structure could have a detrimental effect on the flexibility of a licensee, since any change in signal structure would potentially nullify any measurements made with the expectation of a different signal structure to be present.

Second, if interference temperature is to be referenced at the receiver, knowledge about the licensed receive antenna is required. This would include antenna location and main-lobe gain, as well as the shape of the antenna pattern, so that off-axis properties can be taken into consideration.

Finally, measurement of interference temperature at any location other than that of the licensed receiver location makes the assumption that the undesired signals and man-made noise are homogeneous in nature. This is not necessarily the case.

These challenges will likely exist no matter how the interference temperature model is implemented, and must be resolved to successfully allow unlicensed use without endangering licensed services.

APPENDIX E

ASSESSMENT OF THE POTENTIAL IMPACT OF INCREASING THE NOISE FLOOR

This appendix provides an assessment of the potential impact the increased noise, as discussed in the Federal Communication Commission (Commission) proposal of the interference temperature model, will have on licensed and unlicensed spectrum users. This assessment considers the link budget for interference from an unlicensed transmitter to a licensed user receiver and the link budget for an unlicensed link. It is assumed that the unlicensed transmitter is constrained to a relatively low equivalent isotropically radiated power level and thus would have to be close to the licensed user receiver to cause interference. The unlicensed transmitter would also have to be close to the unlicensed receiver to establish a communications link. Under this transmitter power constraint the elevated, background noise (N_e) shown in Figure 1 of the Commission's Notice of Inquiry can be considered constant over the area of concern.[1]

In order for the unlicensed transmitter not to interfere with the licensed service the following link budget constraint must be satisfied:

$$P_{TU} - C_{U\text{-}L} - N_e = (I/N)_L + L_{ML} \qquad \text{(E-1)}$$

where:

P_{TU} is the transmitter power of the unlicensed device;
$C_{U\text{-}L}$ is the coupling loss from the unlicensed transmitter to the licensed receiver;
N_e is the elevated background noise;
$(I/N)_L$ is the required interference-to-noise ratio for satisfactory performance of the licensed link;
L_{ML} is the available link margin for the licensed service.

The coupling loss includes antenna gains of the licensed and unlicensed transmitters and receivers, propagation losses, and any other additional losses (e.g., foliage, insertion). The link margin includes gains that are unique to the system, such as processing gain and represents the desired signal in excess of the minimum required signal.

Equation E-1 can be rearranged to determine the maximum allowable power level of the unlicensed device:

$$P_{TU} = (I/N)_L + C_{U\text{-}L} + L_{ML} + N_e \qquad \text{(E-2)}$$

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1. *Establishment of an Interference Temperature Metric to Quantify and Manage Interference and to Expand Available Unlicensed Operation in Certain Fixed, Mobile and Satellite Frequency Bands*, Notice of Inquiry and Notice of Proposed Rulemaking, ET Docket No. 03-237, 18 F.C.C. Rcd. 25309 (2003).

If the unlicensed link is to satisfy the performance requirement, then the following link budget must be satisfied:

$$(P_R/N)_U = P_{TU} - C_{U\text{-}U} - L_{MU} - N_e \qquad \text{(E-3)}$$

where:

$(P_R/N)_U$ is the required signal-to-noise ratio for satisfactory performance of the unlicensed link;
$C_{U\text{-}U}$ is the coupling loss from the unlicensed transmitter to the unlicensed receiver;
L_{MU} is the available link margin for the unlicensed service.

Substituting Equation E-2 into Equation E-3 results in:

$$(P_R/N)_U = (I/N)_L + C_{U\text{-}L} + L_{ML} + N_e - C_{U\text{-}U} - L_{MU} - N_e \qquad \text{(E-4)}$$

The elevated, background noise level cancels out in Equation E-4. Therefore, the performance capabilities of the unlicensed device link are not impacted by an increasing noise floor. This is not an unexpected result. The increase in the noise floor does allow higher transmitter power as shown in Equation E-2; however, this higher transmitter power does not improve the performance of the unlicensed link as this unlicensed signal has to compete with the same increased noise level for satisfactory reception as shown in Equation E-3. The result is shown in Equation E-4 as performance that is independent of the elevated noise floor. This phenomenon needs further study before unlicensed devices are permitted to operate at higher-power levels based on consideration of an elevated noise level.