Before the
Federal Communications Commission
Washington, D.C. 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	)	

SUMMARY

The essential concept described in the above-referenced Notice of Inquiry (FCC 03-289) is the idea of regulating interference by limiting received power levels instead of limiting transmitted power levels. This is the fundamental technical concept required for new spectrum access methods.

The FCC's proposed "Closed-Loop" Interference Temperature architecture has significant technical obstacles, primarily the need for a vast number of monitoring sites. An "Open-Loop" Interference Temperature architecture similar to that proposed by the FCC, however, is practical and would achieve the goals of:

- Efficient spectrum access,
- Greater certainty regarding the maximum permissible interference,
- Greater protections against harmful interference that could be present in the frequency bands, and
- Higher transmit power levels than are currently authorized.

A detailed understanding of man-made noise properties is not critical to the initial employment of the Interference Temperature concept. An initial Interference Temperature limit based on achievable receiver noise figures is a low risk starting point. We suggest the use of a value of 3 dB below the typical noise figure (NF) of the Affected Receivers in a band in business, residential and rural areas.

The Fixed Satellite bands (6525-6700 MHz and 12.75-13.25 GHz) suggested for initial testing have disadvantages for demonstrating the general concept. It would be better to choose bands for the initial testing in which the Affected Receivers should are

both fixed and terrestrial, the frequency is below 2,000 MHz and there is low spectrum occupancy.

1 Introduction

Shared Spectrum is a newly formed company developing broadband wireless equipment optimized for secondary spectrum markets applications. As noted by the Commission[1], there is no equipment on the market now with the flexibility and capability to facilitate the use of available spectrum for a broad range of services. Our goal is to offer technology and equipment to fully realize the potential of the secondary spectrum market as rapidly as possible. The technology to accomplish this could be fielded in a few years, but regulatory issues (technical and spectrum availability) now limit its development.

Shared Spectrum has conducted extensive spectrum occupancy surveys that indicate that spectrum utilization is low in most bands, even in urban areas. We believe that the problem is access to spectrum, and not of spectrum shortage.

Shared Spectrum believes that advances in broadband wireless network technology being developed by the Department of Defense along with the Commission's Spectrum Policy Task Force's (SPTF) recommendations will provide a profound improvement to wireless communications over the next few years. These advances enable current and future wireless systems to avoid causing interference and to be tolerant of interference. The Task Force's concept of Interference Temperature enables dynamic, adaptive spectrum use that would solve the spectrum access problem. These new developments will lead to a very large increase in the widespread availability of high capacity wireless communications in both urban and rural regions and provide a significant cost reduction due to reduced spectrum acquisition costs. We applaud the Commission's forward thinking on this issue.

Shared Spectrum is developing adaptive methods to control transmitter power that would enable secondary use to maintain a specified Interference Temperature at the Primary transceiver. We believe our progress in this area can contribute significantly to the practical implementation of the Interference Temperature concept introduced in the SPTF report.

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[1] *Promoting Efficient Use of Spectrum Through Elimination of Barriers to the Development of Secondary Markets*, FCC 00-402, Para. 4.

2 New Approach Interference Management Approach Based on Receiver Levels Rather Than Transmitter Levels

The Commission's "Interference Temperature" concept of regulating interference by limiting received power levels instead of limiting transmitted power levels is the fundamental technical concept required for new spectrum access methods. It will enable much greater spectrum access by allowing transceivers to estimate dynamically interference-related parameters to determine appropriate transmit frequencies and power levels. In contrast, the present method sets the transmit frequencies and power levels for all scenarios by considering the interference in the worse case scenario (based on conservative analysis assuming the worse case for all interference related parameters). Use of this very conservative regulatory approach has led to the very low spectrum utilization that exists today. This difficulty was unavoidable before the development of low power, low cost computing and broad bandwidth RF devices. These technology shortfalls, however, don't exist any longer.

The functional elements related to interference to an "Affected Receiver" by a transmitter are shown in Figure 1. These elements are used to determine the interference between a "Transceiver" and the "Affected Receiver", which then can be used to determine what transmit frequency and power level is acceptable. The transmitter characteristics include the power level, emission type, bandwidth, duty cycle, spurious emissions and other characteristics. The propagation loss between the Transceiver and Affected Receiver then determines the undesired signal level at the Affected Receiver. When there are multiple transmitters, there will be a cumulative effect that will depend on the number of transmitters, their duty cycle, and the propagation conditions. This undesired signal is input to the Affected Receiver along with the desired "Licensed Signal" and noise from the environment. The noise consists of pre-amp thermal noise, natural noise, and man-made noise.

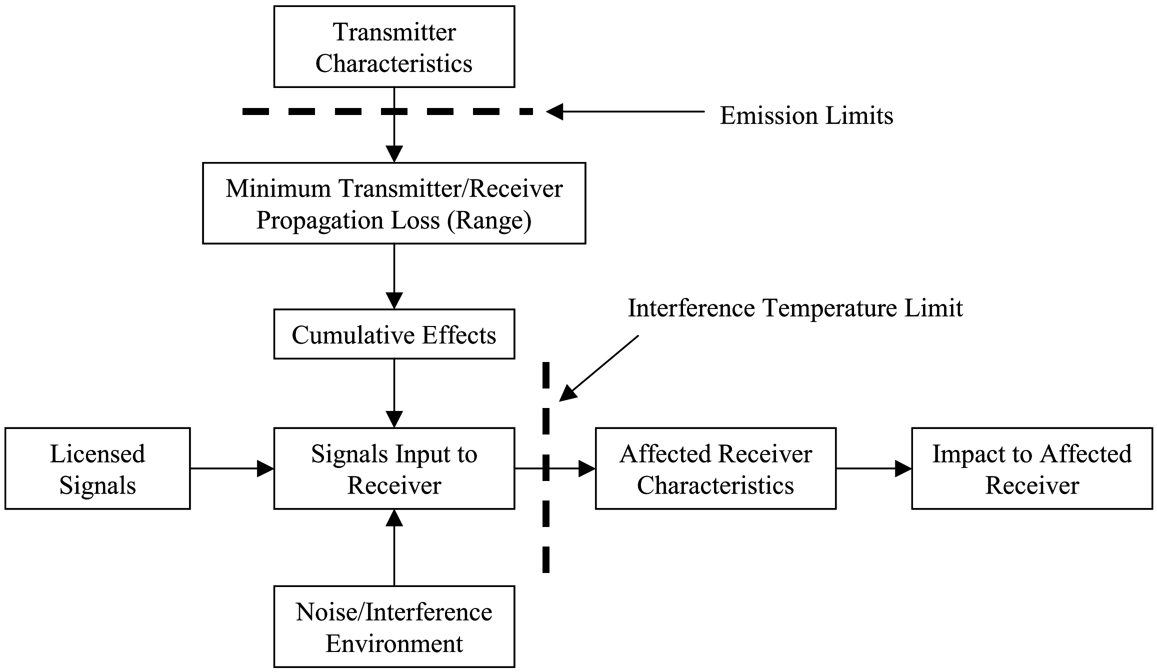

Figure 1 Elements related to interference and different regulatory methods (Emission Limits and Interference Temperature Limit).

Currently the FCC minimizes interference by limiting the transmitter characteristics. These Emission Limits were premised on historical analyses that involve estimating the above functional elements (propagation effects, cumulative effects, Licensed signal characteristics, the noise environment, and the Affected Receiver characteristics). Because of the wide range of potential radio usage, there is large uncertainty in the functional element values, and the FCC must use conservative values. Using overly conservative values greatly limits spectrum use, and is the root cause of the low spectrum usage seen today.

Under its new Interference Temperature concept, the FCC proposes to minimize interference by limiting the level of undesired signal to the Affected Receiver (see Figure 1). The fundamental difference is that it enables the transmitter to estimate some or all of the functional elements (propagation effects, cumulative effects, Licensed signal characteristics, the noise environment, and the Affected Receiver characteristics), and then adjust its transmission characteristics to avoid interference. Instead of making worse case assumptions in all instances, the actual conditions can be used.

3 "Closed-Loop" Interference Temperate Architecture

The FCC proposes for discussion a "Closed-Loop" Interference Temperature Architecture as shown in Figure 2. Monitoring sites that surround the Affected Receiver would be setup. The signal levels at the monitoring sites would be measured, and this information would periodically be reported back to the Transceiver. The data would contain measurements of the Transceiver's signal, which would be used to estimate the propagation Transceiver-Affected Receiver propagation loss. The data would also include measurements of the ambient noise level, which could be used to set the Transceiver's power level so that this signal power at the Affected Receiver would be well below the received noise power.

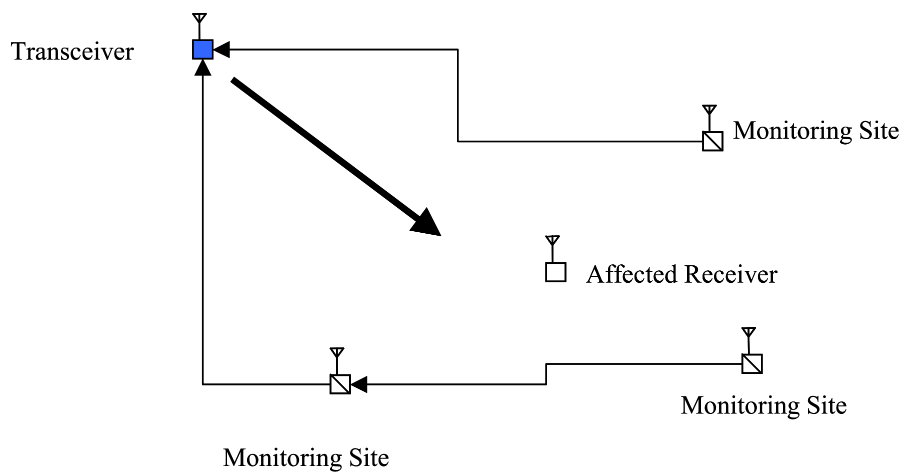

Figure 2 Potential "Closed Loop" Interference Temperature system.

The difficultly with this approach is the propagation loss between the Transceiver and the Affected Site significantly varies with position. The Transceiver-to-Monitoring site propagation loss can be 50 dB to 60 dB different than the Transceiver-to-Affected Receiver propagation loss, even if the Monitoring Site is in close proximity to the Affected Receiver site.

In certain scenarios, the Monitoring approach will work. The conditions are:

- The Monitoring Sites are located at elevated locations compared to the Affected Receiver,
- There are enough Monitoring Sites that surround the Affected Receiver, and
- The Transceiver-to-Affected Receiver distance is much larger that the Affected Receiver-to-Monitoring Site distance.

These conditions limit the applicability of the technique to a limited number of cases. Spectrum sharing in the Broadcast band using high power (~ 5W) Transceivers is a scenario where the Closed Loop architecture is practical. Shared Spectrum Company is developing a system for this application.

Because of the limited applicability and the practical difficulties (cost of the Monitoring Sites, getting the data back to the Transceiver, and calibrating the Monitoring Sites), we believe that the Closed-Loop architecture is workable in only a few scenarios, and should not be the basis for using the Interference Temperature concept.

4 Open Loop Architecture

The Open Loop Interference Temperature Architecture (Figure 3) is a practical approach that is widely applicable. In this approach, the Affected Receiver is assumed to have a transmitter associated with it. Transceiver 1 measures the amplitude of the signal transmitted by the Affected Receiver, and the signals from other transceivers (i.e. Transceiver 2). This information is used to estimate the interference elements shown in Figure 1.

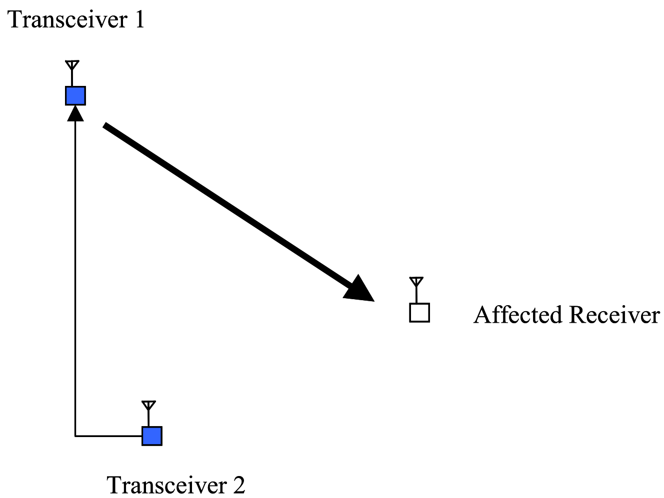

Figure 3 Alternate "Open Loop" Interference Temperature system.

Figure 3 shows the Open Loop Interference Temperature system logic. After selection of a frequency, the Transceiver measures the spectrum over a time period. This includes the co-channel, adjacent channel, harmonic, and any other frequencies that need to be examined as part of the required regulatory spectrum behavior. These measurements are used to estimate the propagation loss to the Affected Receiver (using an assumed value of the Affected Receiver's transmit power ($P_{Affected}$)), and to estimate the number of other Transceivers in the area.

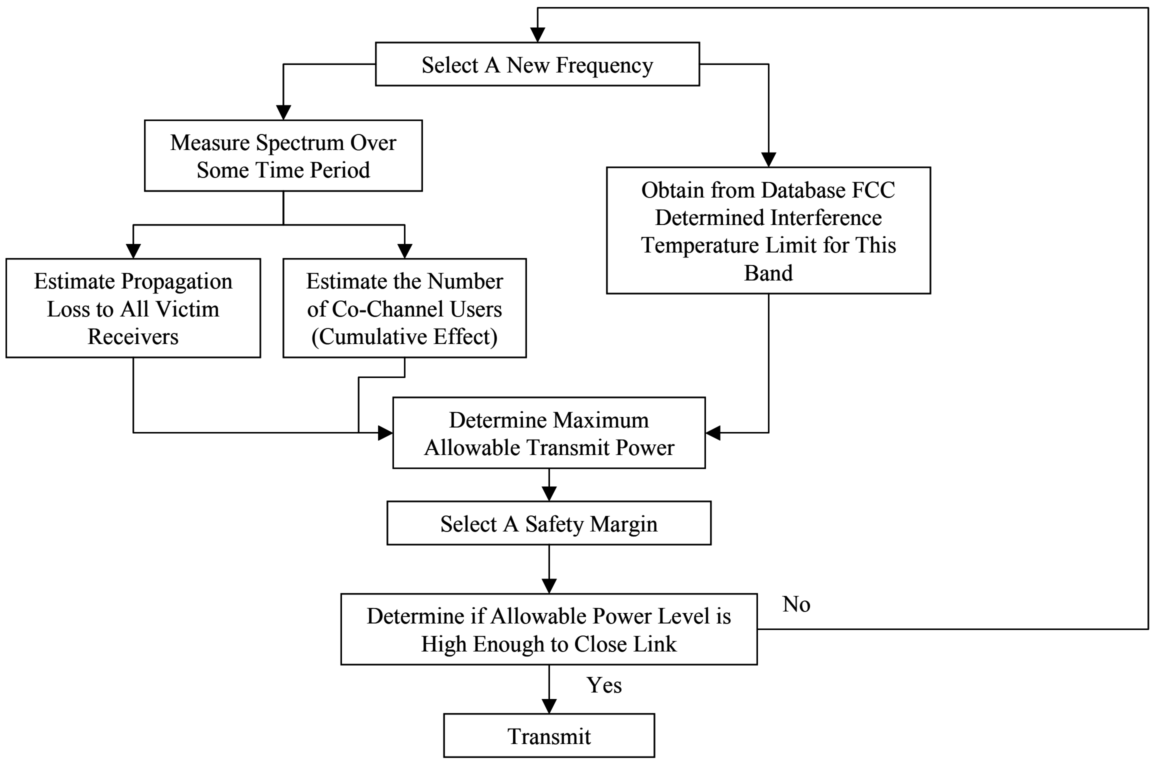

Figure 4 Flow diagram showing "Open Loop" Interference Temperature system logic.

The Transceiver's maximum allowable transmit power is then

$$P_{max\ TX} = P_{allowable\ interference} + P_{Affected} - P_{measured} \qquad (1)$$

The allowable interference power ($P_{allowable\ interference}$ in dBm) is related to the Interference Temperature (Ti) if the Affected Receiver and the Transceiver have the same signal bandwidths (B).[2] In the equation below, k is Boltzmann's constant (1.38 x 10^{-23} J/K) and T_I is the Interference Temperature in Kelvin.

$$P_{allowable\ interference} = 10*\log10(k * T_I * B) + 30 \qquad (2)$$

Depending on the spectrum behavior used, the Transceiver's maximum allowable transmit power is minimum of the values calculated for the co-channel and

[2] The Transceiver' maximum transmit power can be increased by the bandwidth ratio if the it's signal bandwidth is larger that than Affected Receiver's signal bandwidth.

adjacent channels (adjusted by the adjacent channel isolation of the Transceiver and the Affected Receiver). The Transceiver's maximum allowable power is then reduced by the estimated number of other users (based on the spectrum's time history measurements).

A safety margin is then used to reduce the Transceiver's maximum allowable transmit power. This accounts for rapid changes in the propagation due to mobility, uncertainties in the assumed value of the Affected Receiver's transmit power ($P_{Affected}$)), and other factors.

If the resulting Transceiver's maximum allowable transmit power is high enough to close the desired link, then the frequency is used. Otherwise, another frequency is selected and the entire process repeats.

5 Interference Temperature Levels

5.1 Interference Sources

There are many types of unintended signals that are input to the Affected Receiver. These include the cumulative power of all distant (not strong enough to demodulate) licensed signals, emissions from proximate electronic devices (computers, power lines, power converters, etc), sideband and harmonic distortion from other transmitters, and receiver pre-amplifier noise.

There have been extensive measurements of unintended, man-made noise signal levels that culminated in the International Telecommunications Union (ITU) noise model[3] and other noise models[4]. These findings show that the median noise level varies with frequency and location (urban, suburban, and rural). Typical noise levels (in units of Noise Figure (dB)) are shown in Figure 5 and Figure 6. These ambient noise levels are high below 1,000 MHz. As shown in Figure 6, the emissions from nearby devices (a vehicle at 50 feet in this example) can increase the noise figure to 40 dB to 50 dB.

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[3] CCIR, "Man-made Radio Noise", Report 258-5, International Radio Consultative Committee, International Telecommunications Union, Geneva, Switzerland, 1990

[4] "Man-Made Noise Power Measurements at VHF and UHF Frequencies", R.J. Achatz and R. A. Dalke, NTIA Report 02-390, December, 2001

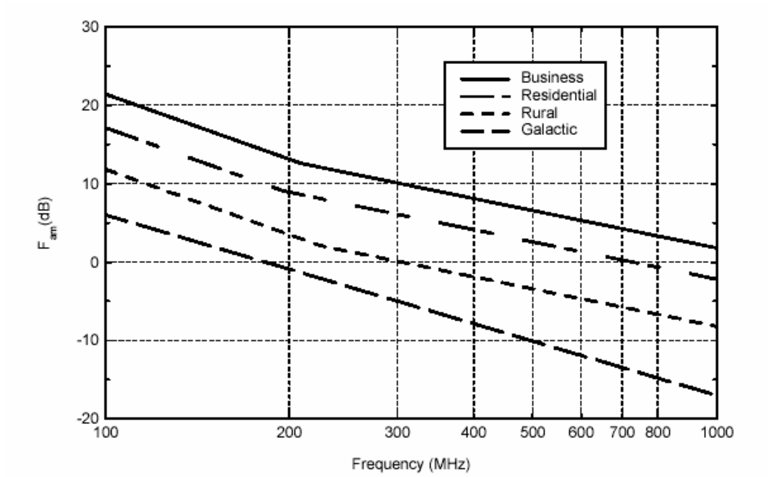

Figure 5 Median value of average noise power expected from various sources (omni-directional antenna near the surface).[4]

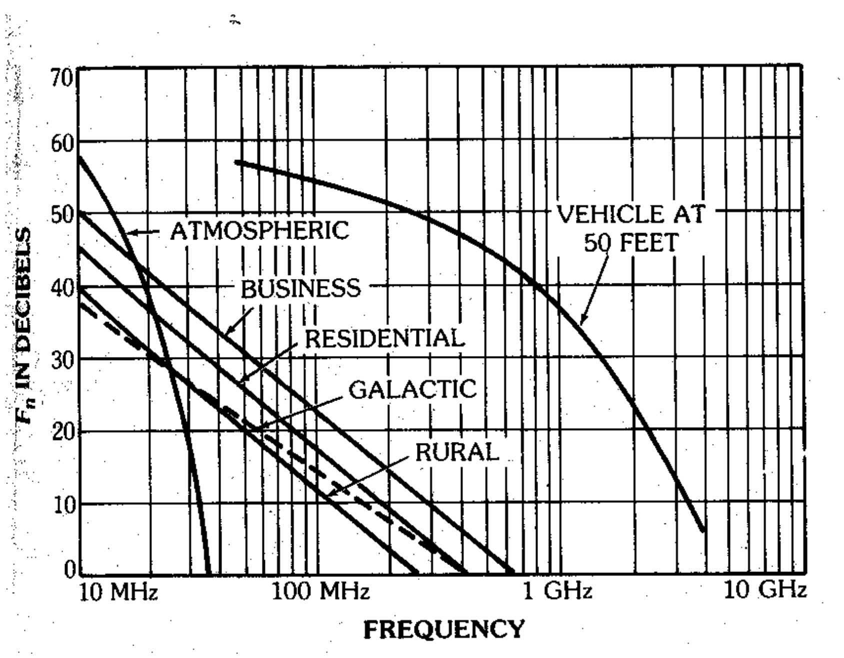

Figure 6 Noise data including large emissions from a vehicle at 50 feet.[5]

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[5] Reference Data for Engineers: Radio, Electronics, Computer and Communications, Eight Edition, page 32-11, Sams Publishing, 1993.

Ambient noise level statistics other than the median values are not well known. Experimental studies indicate that the noise levels in specific scenarios don't necessarily follow the ITU model. For example, in the HF band the ambient noise can be low in urban areas and can be high in rural areas.[6] The dominant noise sources in this study were power lines, which was time varying and erratic. Furthermore, the noise levels inside buildings, where the vast majority of consumer wireless devices are used, is not reported in the literature. Shared Spectrum's measurements indicates that these noise levels will be much higher than the levels shown in Figure 5 and Figure 6 because of the proximity of computers and other devices.

We believe that if detailed noise statistic experiments were made at a large number of locations, that the results would be similar to the hypothetical results shown in Figure 7 and Figure 8. These estimates are based on Shared Spectrum's experience making spectrum occupancy measurements over the last several years, and are representative of frequencies below 500 MHz. Figure 7 shows the number of locations versus the ambient median noise level in dBm/Hz (assuming that the system has a 7 dB noise figure), while Figure 8 shows the cumulative probability of cases with noise level less than the noise level shown in the X-axis. The high noise cases have strong emissions from proximate electronic devices, while the low noise case are dominated by the receiver's RF front-end noise (pre-amplifier noise, cable, filter, and RF switch losses).

[6] "An Examination of Man Made Radio Noise at 37 HF Receiver Sites", W.R. Vincent, R.W. Adler, and G.F. Munsch, Navel Postgraduate School Report, NPS-EC-03-006, November 2003.

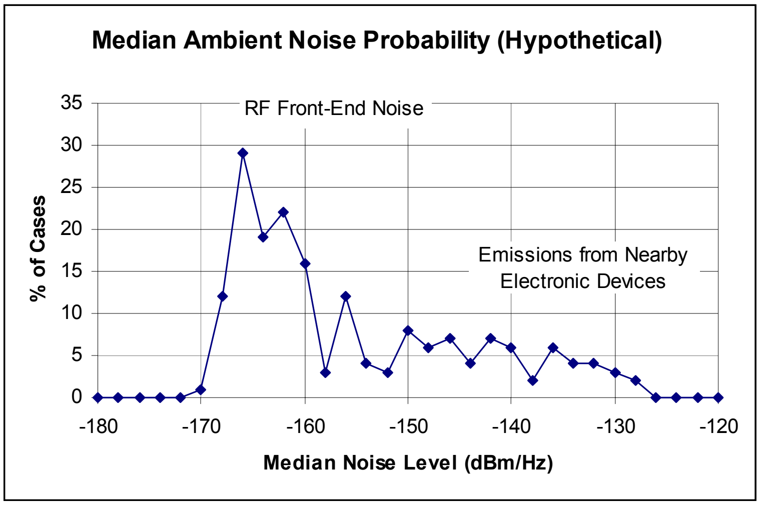

Figure 7 Hypothetical received noise level probability for multiple test locations versus median noise level.

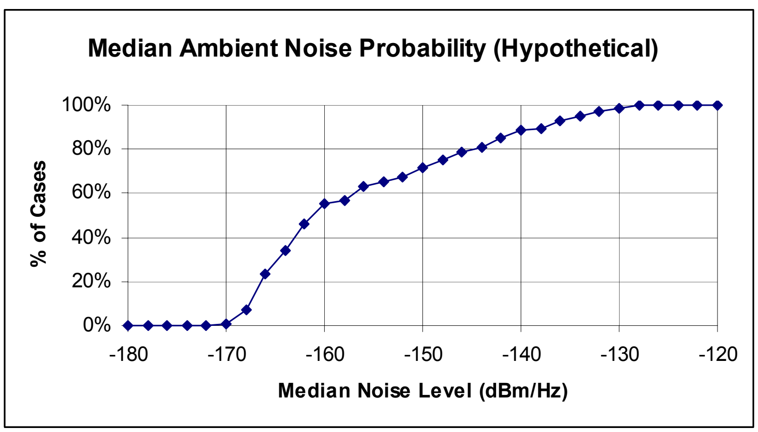

Figure 8 Hypothetical received noise level cumulative probability for multiple test locations versus median noise level.

The median noise level in this example in –161 dBm/Hz, which is a noise figure of approximately 13 dB. Comparing with Figure 5, this corresponds to the case of a frequency of 200 MHz in a “business” area.

The important point is that in many locations, the noise level will be set by RF-front end noise. The probability of this will be high enough, that the existing spectrum users will argue for a low Interference Temperature.

5.2 Interference Temperature Limit

We believe that the Interference Temperature Limit should be approximately 3 dB below the typical effective input power caused by the Affected Receiver's pre-amplifier in a band. Table 1 shows a list of pre-amplifier noise values and the associated Interference Temperature limits. The 3 dB value provides a balance between the impact to the Affected Receiver and ability of the Transceiver to transmit reasonable power levels. In bands where the ambient noise level is low and the Affected Receiver link margins are low (high bandwidth satellite downlinks for example), the 3 dB value would be increased to a larger value or the Interference Temperature operation would not be authorized.

Table 1 List of Pre-amplifier Noise Values and Interference Temperature Limits Assuming a 3 dB Margin

Pre-Amp Noise Power (KTB) (dBm/Hz)	Pre-Amp Noise Temperature (K)	Pre-Amp Noise Figure (dB)	Interference Temperature Margin (dB)	Interference Temperatuce Noise Power (dBm/Hz)	Interference Temperature (K)	Interference Temperature Noise Figure (dB)
-200	0.73	0.01	3	-203	0.37	0.01
-198	1.15	0.02	3	-201	0.58	0.01
-196	1.83	0.03	3	-199	0.92	0.01
-194	2.90	0.04	3	-197	1.46	0.02
-192	4.60	0.07	3	-195	2.32	0.03
-190	7.28	0.11	3	-193	3.67	0.05
-188	11.55	0.17	3	-191	5.82	0.09
-186	18.30	0.27	3	-189	9.22	0.14
-184	29.00	0.41	3	-187	14.61	0.21
-182	45.96	0.64	3	-185	23.16	0.33
-180	72.84	0.97	3	-183	36.70	0.52
-178	115.45	1.46	3	-181	58.17	0.79
-176	182.98	2.12	3	-179	92.19	1.20
-174	290.00	3.01	3	-177	146.11	1.77
-172	459.62	4.12	3	-175	231.57	2.55
-170	728.45	5.46	3	-173	367.01	3.55
-168	1154.51	6.97	3	-171	581.67	4.78
-166	1829.78	8.64	3	-169	921.88	6.21
-164	2900.00	10.41	3	-167	1461.08	7.81
-162	4596.19	12.27	3	-165	2315.66	9.54
-160	7284.47	14.17	3	-163	3670.08	11.35
-158	11545.11	16.11	3	-161	5816.68	13.23
-156	18297.76	18.07	3	-159	9218.81	15.16
-154	29000.00	20.04	3	-157	14610.84	17.11
-152	45961.90	22.03	3	-155	23156.62	19.08
-150	72844.71	24.02	3	-153	36700.76	21.06
-148	115451.08	26.01	3	-151	58166.79	23.04
-146	182977.63	28.01	3	-149	92188.15	25.04
-144	290000.00	30.00	3	-147	146108.37	27.03
-142	459619.03	32.00	3	-145	231566.15	29.03
-140	728447.07	34.00	3	-143	367007.62	31.03

The Interference Temperature Limit adopted by the FCC would be the level of interference protection that a Primary user would be afforded. Additional Transceivers would be allowed to radiate if the sum of the power from all of these devices plus the power from all other undesired sources was less than the Interference Temperature Limit. The Interference Temperature Limit should be set high enough to enable the maximum number of Transceivers to use the spectrum as long as it does not cause more than minimal impact to the existing spectrum users.

Figure 9 shows the increase in input noise power caused by the addition of the Transceiver’s signal versus the Transceiver’s signal’s power level (relative to the noise power). If the additional signal power is equal to the original noise level, then the total noise will be 3 dB higher. If the additional signal power is 3 dB less than the original noise level, then the total noise will be 1.76 dB higher.

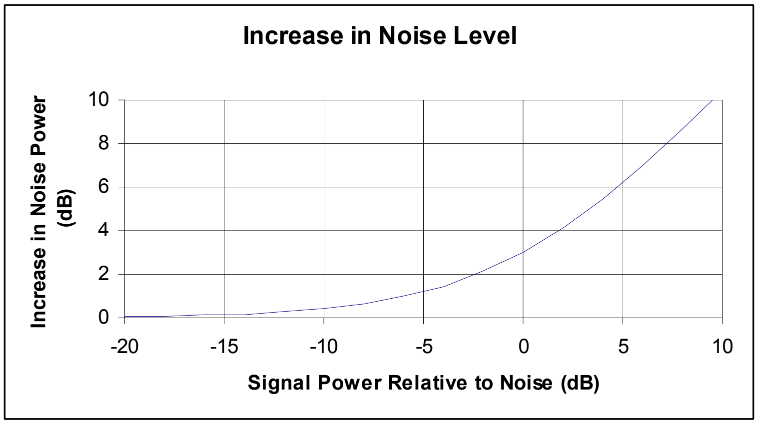

Figure 9 Increase in noise power caused by an additional signal versus the additional signal power (relative to the noise level).

The impact to a communications system of an additional signal that is 3 dB less than the noise level will be negligible in most cases in the above example. Figure 10 shows the cumulative number of cases (Affected Receiver locations) versus the median noise level (Affected Receiver NF=7 dB). Also shown is the same curve but for the system with an additional Transceiver signal with a power level (-171 dBm/Hz or 3 dB less than the original noise power of -168 dBm/Hz). The additional signal significantly increases the noise floor in only a few cases.

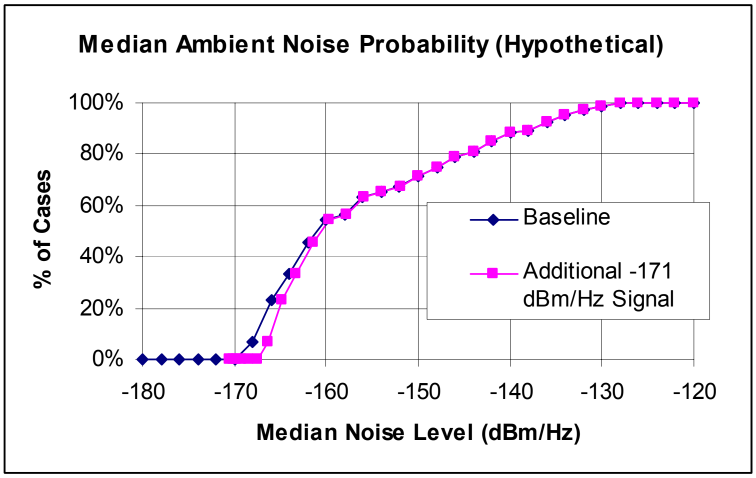

Figure 10 Increase in noise level versus additional signal power.

The additional Transceiver signal affects a smaller percentage of users than is indicated by Figure 10. This small increase in noise level will cause degradation to the Affected Receiver only if:

- The Affected Receiver link is operating at near maximum range,
- There are no other co-channel, licensed users that would tend to increase the noise level (perhaps more than the Transceiver signal),
- The Affected Receiver is outdoors (where the above man-made noise level was assumed); otherwise high man-made noise values would exist.
- There is a Interference Temperature Transceiver in the region,
- The Interference Temperature Transceiver needs to operate at the full power allowed,

We believe that the probability of all of these events simultaneously occurring is negligible.

The above Interference Temperature value is the limit on the received power of all Transceivers in the region using the Interference Temperature method. Cumulative effects need to be compensated for by the Transceiver as shown in Figure 4.

5.3 Interference Temperature Metric

Interference Temperature should be a measure of signal power per unit bandwidth. Units of Watts/Hz, dBm/Hz or Kelvin can be used. The total noise power (N) over a frequency range (b) is equal to:

$$N=kTb \text{ (W)}$$

Where k is Boltzmann's constant (1.38×10^{-23} J /K).[7]

We believe that the Interference Temperature Limit should be initially set to a low value, where the noise is dominated by RF-front end noise. In this case, the standard gaussian noise detectors and other measurement methods are adequate.

5.4 Need for Additional Noise Measurements

A detailed understanding of man-made noise properties is not critical to the initial employment of the Interference Temperature concept. An initial Interference Temperature limit based on achievable receiver noise figures is a low risk starting point.

There have been numerous studies of ambient noise levels that establish that the median noise level below 1,000 MHz is well above the noise levels caused RF front-ends.[6] Since the median ambient noise level is high, in the majority of situations most receivers are not limited by RF-front end noise levels.

It is also well known that a significant number of Affected Receivers enjoy low levels of ambient noise level. This number is probably high enough, that the initial Interference Temperature limit values will initially be set by these few cases. Whether these cases occur 1% of the time, 5% of the time or some percent of the time, is irrelevant.

These Affected Receivers that are not limited by high ambient noise levels are those that happen to be located far from electronic devices with significant emissions. We believe that it is not practical for an Interference Temperature Transceiver to

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[7] Antennas, John D. Krauss, page 847.

determine if an Affected Receiver is proximate to an electronic device or other noise source, because these effects are short-range (100's of meters).

Thus, the Interference Temperature values need to be initially set by RF front-end noise levels. Additional noise measurements can then be used to determine in what scenarios the number where the Affected Receivers that are limited by only RF-front end noise is insignificant. In these cases, the FCC can then increase the Interference Temperature to high levels.

6 Proposed Bands for Initial Testing

The Fixed Satellite bands (6525-6700 MHz and 12.75-13.25 GHz) proposed by the FCC for initial testing have many disadvantages for demonstrating the Interference Temperature concept.

6.1 Band Disadvantages

These bands have Affected Receivers that are located in space, and therefore can't use the FCC's Closed-Loop architecture because of the expense of building new satellites to act as Monitoring Receivers.

The Affected Receivers in these bands are also line-of-sight to a large fraction of the earth, and thus an Interference Temperature Transceiver is not likely to be in close proximity to other Interference Temperature Transceivers. This it will be hard to use receive-only methods to estimate the number of cumulative transmitters (as shown in Figure 4). Scenarios with the Affected Receivers and the Transceivers in similar terrestrial locations make estimating the cumulative factor easier.

These Fixed Satellite bands don't offer significant RF performance or economic benefits that make it worth the private investment to develop and test the Interference Temperature concept. These Fixed two Satellite bands have poor propagation characteristics in terrestrial applications. There are already unlicensed and other bands available that provide similar propagation performance.

6.2 Recommended Band

Better bands for the initial Interference Temperature testing should have the following characteristics:

- The Affected Receivers should be both fixed and terrestrial.
- The band frequency should be below 2,000 MHz, so that it would have better propagation conditions than the currently used unlicensed bands.
- The band should have low spectrum occupancy.

Respectfully submitted,

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