Before the
Federal Communications Commission
Washington, DC 20554

In the Matter of	)	
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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	)	ET Docket No. 03-237

To: The Commission

COMMENTS

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SUMMARY

The "interference temperature" metric was invented by the Commission's Spectrum Policy Task Force. It was not, and is not, used in wireless system design or engineering. Although it sounds scientific, it is not a scientific concept — it is not even based on science.

The premises given for consideration of this new rule are incorrect. First, the Commission says, it is needed for transitioning to real-time interference management. However, cellular and PCS networks already employ real-time interference management, and requiring these networks to share with unlicensed users based on an entirely different and unproven technique for real-time interference management would be disastrous. Second, the Commission says, the new rule would give licensed operators "certainty" regarding interference. The only certainties are that allowing new unlicensed users to access licensed spectrum *will* cause increased interference, regardless of the metric used for governing such access, and that the value of the licensed spectrum for accommodating public communications needs will be diminished. The Commission must maintain a firm distinction between exclusively licensed spectrum and spectrum available for unlicensed operation, rather than introduce ambiguity with this unproven and untested concept.

While the objective of an interference temperature rule would be to allow more unlicensed use of spectrum, the Commission does not even attempt to show why the more than 700 MHz of spectrum already available for unlicensed use (many times the amount available for licensed cellular and PCS) is insufficient. If the Commission believes that an interference temperature rule will allow it to pack more users into a band, it should start by applying it to the bands already allotted for unlicensed use. It should not subject licensed bands to the chaos and congestion that it perceives to exist in unlicensed bands. If the Commission applies the interference metric to licensed bands and discovers that unlicensed underlays *do* interfere with licensed use, it will be too late, with potentially millions of devices in use and causing interference.

The shift to an interference temperature rule would represent a step backward in how wireless services are regulated. The Commission has generally taken a flexible, market-oriented approach to cellular and PCS licensees, predicated on exclusive licenses defined in spectral and geographic terms. The interference temperature metric would subject these licensees instead to a command-and-control regulatory scheme that would limit licensees' flexibility, contrary to the intentions of the Spectrum Policy Task Force.

The Commission would convert exclusive licenses into hybrid shared licenses by applying an interference temperature rule. This would upset business plans involving billions of dollars in investments. It would ensure that the licensee will increasingly face "worst case" interference conditions, and would take away the licensee's ability to avoid or manage such conditions through interference management, use of alternative technologies, and other engineering approaches. Moreover, it would preclude the licensee from implementing technologies that may improve efficiencies and allow reception of its licensed service at levels where effective communication may not *currently* be possible. In essence, the interference temperature analyzes the "worst-case" scenario for receiver operations under *current* technology and usage conditions and precludes licensees from addressing this scenario as technology evolves. The Commission must not take steps that would potentially require licensees to diminish their efficiency or service quality or increase the cost of providing service to their customers.

Interference temperature is purely a regulatory creation, not a scientific concept. Moreover, it has not been adequately or rigorously defined. The Commission defines it by analogy to

"antenna temperature," but does not cite any technical references, studies, or standards; only a website providing a generic explanation of antenna temperature, and *the Commission does not use that site's formulas in defining interference temperature.* Apparently, the Commission has borrowed only the concept of expressing a power spectral density in Kelvin instead of Watts per Hertz, because that is all the Commission's definitions accomplish. An interference temperature conveys no more information than the number of watts of noise or interference received within a defined bandwidth — expressing this in Kelvin adds nothing but a different unit. The Commission's metric, however, fails to take into account the directional characteristics of the receive antenna and its orientation with respect to a source of interference. The exact definition of "interference temperature" and how it may relate to antenna temperature, the noise floor, or interference levels remains unclear.

The Commission is also imprecise about how, where, and when interference temperature should be measured in its scheme, even though it recognizes that it has meaning only with respect to a particular receiver. Under none of the scenarios explored would unlicensed transmitters be able to determine the interference temperature of the affected receivers. Moreover, a measurement of the radio frequency power within a given bandwidth will contain desired signals as well as noise and interference, making it difficult for an "interference temperature thermometer" to work. And if interference temperature were actually determined at the affected receive sites, dedicated spectrum would be needed to get that information to unlicensed devices in real time, which would seem to undercut the reason for measuring interference temperature in the first place; if there were sufficient spectrum for this, the Commission would be better advised to allocate it for unlicensed use.

The Commission asks whether a modest increase in the noise floor would constitute harmful interference. The short answer is that even a very small increase in the noise floor would disrupt the operations of a network operating at or near the noise floor, reducing quality, capacity, and coverage. To restore such a network to its previous level of performance would require expensive overbuilding. Thus, any increase in the noise floor due to unlicensed operation should be deemed harmful interference.

The Commission's approach to interference temperature would effectively present licensed operators with a worst-case scenario all the time, precluding the use of efficient technologies. The Commission does not attempt to assess any benefits that may outweigh this substantial cost to the licensees and the public. It poses an economic tradeoff between known goods and services, highly valued by the consumers and producers who utilize them, and a speculative set of goods and services, whose identity is unknown and whose economic value and successful realization are unknown.

In addition to its Notice of Inquiry, the Commission has also proposed to adopt rules for interference temperature-based unlicensed access to certain licensed bands. Given that the most fundamental aspects of interference temperature are still unknown, rulemaking is inappropriate. Moreover, the Commission's analysis of the interference potential of such unlicensed sharing is inadequate. Cingular and BellSouth provide a detailed analysis of the interference posed to microwave operations at 6 GHz. Moreover, no test in licensed spectrum is needed, given that the Commission could have tested its concept in the 5 GHz UNII bands or in bands being opened to nongovernmental use.

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COMMENTS

Cingular Wireless LLC ("Cingular") and BellSouth Corporation ("BellSouth") hereby submit their comments in response to the Commission's Interference Temperature *Notice of Inquiry and Notice of Proposed Rulemaking.*[1]

INTRODUCTION

On November 7, 2002, the Commission's Spectrum Policy Task Force ("SPTF") issued its Report,[2] urging the Commission, among other things, to shift from analyzing interference based on transmitter operations "toward operations using real-time adaptation based on the actual radio frequency ("RF") environment through interactions between transmitters and receivers."[3]

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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,* ET Docket 03-237, *Notice of Inquiry and Notice of Proposed Rulemaking,* 18 F.C.C.R. 25309 (2003) (*NOI/NPRM*), *summarized,* 69 Fed. Reg. 2863 (Jan. 21, 2004), *correction,* 69 Fed. Reg. 5945 (Feb. 9, 2004).

2 The *Spectrum Policy Task Force Report* (Nov. 7, 2002) (*SPTF Report*) was never published in the FCC Record or the Federal Register. It is available for download from the FCC website at <http://hraunfoss.fcc.gov/edocs_public/attachmatch/DOC-228542A1.pdf>. Given the importance of the *SPTF Report,* Cingular urges the Commission to publish this document in the FCC Record for future reference. Citations to the *SPTF Report* herein are to the printed page numbers from the Adobe Acrobat version cited above.

3 *Id.* at 27.

The SPTF said that the Commission should "specify a more accurate measure of interference that takes into account the cumulative summation of all the undesired RF energy available to be captured by a particular receiving antenna for delivery to the receiver."[4] To accomplish this objective and to move toward "real-time measurements," the SPTF advocated the use of "a new metric, 'interference temperature,' to quantify and manage interference."[5] The SPTF envisioned the setting of different interference temperature thresholds for "for each band, geographic region or service," and said that "these thresholds should be set after the Commission has reviewed the condition of the RF environment in each band."[6] It continued:

> This review should include actual spectrum measurements of the RF noise/interference floor. In addition to obtaining better data regarding the noise floor, the Commission should adopt a standard methodology for measuring the noise floor.[7]

The interference temperature ("IXTemp") concept was completely new. It was not an existing engineering metric, had never been proposed in a scientific or engineering journal, and did not emerge from technical standards bodies. The SPTF created this new metric by analogy to the concept of "antenna temperature" and provided two alternative definitions for it.[8] The SPTF provided no technically rigorous description of how it was derived or how the SPTF envisioned measuring it or setting the IXTemp thresholds.

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4 *Id.*

5 *Id.*

6 *Id.* at 28.

7 *Id.*

8 *Id.* at 27 & n.28.

Accordingly, when the Commission invited comment on the *SPTF Report,*[9] twenty-eight parties filed comments on the IXTemp concept.[10] Cingular filed extensive comments on January 27, 2003 that addressed legal, policy, and engineering issues concerning IXTemp at length.[11]

In addition, Cingular and other carriers commissioned V-Comm, L.L.C. to conduct a noise floor study in the 1900 MHz PCS band after completion of a similar cellular noise floor study. The PCS noise floor study, which cross-referenced the cellular study that had been filed in another proceeding, was filed in the SPTF docket by V-Comm on September 16, 2003.

In the *NOI/NPRM,* the Commission is attempting to gather more information to understand exactly what "interference temperature" is and how it could eventually be used to assist in the process of spectrum management. The *NOI/NPRM* never acknowledges, much less addresses, the noise floor studies that V-Comm submitted,[12] even though both the SPTF and the Commission's Technological Advisory Council ("TAC") recommended that the Commission take the time to study the noise and interference environments that exist throughout the country. In fact, the Commission has not completed any of the preliminary steps that were suggested by the SPTF. There are many issues that must be addressed before a noise-monitoring or IXTemp-monitoring network could be deemed technically feasible and capable of providing meaningful information to users of a particular spectrum band.[13]

The *NOI/NPRM* also fails to address comments filed by the twenty-eight parties who addressed the IXTemp concept (including Cingular), other than to note that a few commenters op-

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[9] Public Notice, *Commission Seeks Public Comment on Spectrum Policy Task Force Report,* ET Docket 02-135, FCC 02-322 (Nov. 25, 2002).

[10] *NOI/NPRM* at ¶ 1 n.1.

[11] Cingular Comments on SPTF Report, ET Docket 02-135 (Jan. 27, 2003).

[12] V-Comm is resubmitting both noise floor studies with its comments in response to the *NOI/NPRM.*

[13] Of course, there must also be some way to fund the building and operation of such a network as well as to develop plans for what would happen should the network fail.

posed use of IXTemp as "impractical and unworkable" or called for further study.[14] The *NOI/NPRM* provides no indication that the Commission has given any consideration to the legal, policy, and engineering issues concerning IXTemp that Cingular and others raised. It addresses the IXTemp as though it were writing on a blank slate.

Before moving forward with rulemakings to consider implementation of the IXTemp concept, the Commission needs to investigate and confront the concepts involved in the evaluation, implementation, and possible measurement of the IXTemp metric. While it might be appropriate at this time to conduct an inquiry on IXTemp as a concept and to address the merits (or lack thereof) of using IXTemp as a spectrum management tool, it is entirely premature to move forward with proposed rules until this generic inquiry has been completed. Importantly, the inquiry cannot be completed until the research and measurement programs advocated by the SPTF, the TAC, and many other commenting parties have been carried out.[15]

The *NOI/NPRM* acknowledges that "a general implementation of the interference temperature approach would involve planning, study of the existing RF noise and interference levels and other factors, and transition processes would take a substantial amount of time to complete."[16] Nevertheless, the Commission now seeks to adopt rules to "establish interference temperature limits and procedures for assessing the interference temperature in specific frequency

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14 *See NOI/NPRM* at ¶ 2 & nn.4-5.

15 For example, the SPTF advised the Commission that "in addition to obtaining requisite data regarding the noise floor, there are many factors that the Commission would need to consider before setting an interference temperature for a particular band. Some potential factors that may be considered are: (1) nature and extent of incumbency; (2) the nature and types of the services (for example, the criticality of services like public safety); (3) the susceptibility of services and existing equipment to interference; (4) state of development of technology; and (5) propagation characteristics." *SPTF Report* at 33.

16 *NOI/NPRM* at ¶ 4.

bands used by fixed satellite uplinks and by terrestrial fixed point-to-point links."[17] Such an approach is premature when none of the studies that are necessary prerequisites to rulemaking have been conducted. Before moving to adopt the concept of an IXTemp metric, more study is required to determine whether this approach is technically feasible and generally worthwhile from a cost/benefit standpoint.

A cautious approach is needed, in particular, with respect to assessing how an IXTemp metric might be applied to bands that are currently used intensively by commercial mobile radio service ("CMRS") providers. CMRS service is relied upon by a majority of Americans and is increasingly important for public safety and homeland security.

The market-oriented flexible geographic licensing model used in the past to manage spectrum use and interference in the CMRS bands has "generally served well to control interference and to facilitate effective use of the spectrum."[18] The Commission's recent move to permit spectrum leasing will further facilitate efficient use of this spectrum, responsive to market forces. For the market-oriented licensing model to work, however, there must be a clear distinction that a band of spectrum is intended for licensed use or unlicensed use but not both. In the case of licensed spectrum bands which are to be auctioned, this level of certainty is exactly what is needed to allow the potential licensees to place an accurate value on the spectrum.

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17 *Id.*

18 *NOI/NPRM* at ¶ 5.

DISCUSSION

I. COMMENTS IN RESPONSE TO THE NOTICE OF INQUIRY

A. The Premises for Using Interference Temperature Are Incorrect

1. Cellular and PCS Networks Already Manage Interference in Real Time, and Unlicensed Units Are Not Compatible With Network Operation

The SPTF advocated using IXTemp as a general long-term strategy for transitioning to an environment where interference is managed in real time based on the interactions between transmitters and receivers.[19] This strategy is misplaced, however, with respect to RF environments that are already characterized by interference management in real time, such as cellular and PCS networks.

All two-way CMRS networks, to varying degrees, employ dynamic power control based on real-time analysis of the interactions between base stations and mobile units in the actual RF environment.[20] Only by using such techniques, tailored to the particular technologies employed, can cellular and PCS networks achieve the high levels of spectral efficiency needed to accommodate today's traffic with acceptable quality and coverage. Moreover, the evolution of today's

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19 *SPTF Report* at 27.

20 The Commission erroneously states that "real-time adaptation based on actual RF environments has not been done in the past." *NPI/NPRM* at ¶ 19. In fact, even the AMPS analog cellular standard approved by the Commission in 1981 was predicated on mobile units and base stations analyzing each others' signals in real time to permit the switch to make determinations as to how calls should be handled; both channel assignments and mobile power levels were to be dynamically controlled from the switch based on real-time data. *See generally* OST Bulletin No. 53, Cellular System Mobile Station – Land Station Compatibility Specification (April 1981), published as Exhibit D to *Cellular Communications Systems,* CC Docket 79-318, *Report and Order,* 86 F.C.C.R. 469, 576 (1981) (subsequent history omitted). All of the digital cellular and PCS standards that have followed in the wake of AMPS have employed increasingly complex real-time adaptation mechanisms to the actual RF environment. For example, CDMA systems modify the power of mobile units 800 times per second in order to equalize the received signal strength of all mobile signals being handled by a given site in real time. In W-CDMA (UMTS) the power control rate is 1500 times per second. GSM systems can modify the frequency of mobile units up to 200 times per second and control the power level 2 times per second to adjust to the changing RF environment in real time.

cellular and PCS networks to provide increasing levels of quality, more extensive coverage, and higher data transmission speeds will require carriers and vendors to continue improving and perfecting various technologies to take advantage of decreases in noise and interference when they occur. In this environment of intensive spectrum use, even brief, momentary increases in noise or interference will adversely affect service.[21]

Layering on top of this a regulatory scheme that allows interference levels to be increased based on a different real-time interference metric is a recipe for disaster. A cellular or PCS network is designed to manage internally-generated interference in accordance with protocols and criteria that establish an appropriate balance of overall system capacity, coverage, and quality. The network cannot control external interference, so when it occurs, the network will attempt to maintain the overall balance of system capacity, coverage and quality to the extent possible. There will be adverse effects, however. For example, external interference on the mobile transmit channels will typically cause the network to order mobile units to increase their transmit power to overcome the interference. Not all mobiles will be able to do so, however, because they may already be operating at or near their maximum power (*e.g.,* handsets in buildings or at the periphery of a cell's coverage). As a result, the system's effective coverage will be decreased due to the interference, leaving dead spots where there would have been adequate coverage without the interference. The interference may also cause an increase in the number of dropped calls or a reduction in the number of calls that can be handled by an affected site.

The *NOI/NPRM* appears to view IXTemp not merely as a long-term strategy for ensuring that interference is managed in real time — a goal that has already been accomplished in broadband CMRS. Instead, it views IXTemp as a vehicle for creating new opportunities for free unlicensed usage of spectrum that is already exclusively licensed, while giving the licensees addi-

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21 *See also* Comments of V-Comm, L.L.C., being filed today ("V-Comm Comments").

tional "certainty . . . in terms of how much interference they will experience."[22] The only "certainty" that application of IXTemp will give incumbent licensees is the certainty that interference levels will increase uncontrollably and that, as a result, the value of their spectrum for accommodating the public's communications needs will increasingly diminish.[23]

2. The Need for Additional Spectrum for Unlicensed Use has not been Shown.

The Commission makes no attempt to justify its objective of creating more and more opportunities for unlicensed spectrum usage, which is its entire premise for employing the IXTemp metric. At this time, and for the foreseeable future, there seems to be adequate spectrum that is assigned to unlicensed devices. This includes the 902-928 MHz band, the 2400-2483.5 MHz band, and the various bands at 5 GHz (*i.e.*, 5.15-5.35 GHz and 5.47-5.875 GHz). In total, these bands occupy more than 700 MHz of spectrum — vastly more spectrum than is available for all CMRS. Furthermore, the recently approved operation of ultra-wideband (UWB) devices allows more than 7 GHz of spectrum (*i.e.*, 3.1-10.6 GHz) for this type of unlicensed operation. From the vast amount of spectrum available for unlicensed operation, there should be no significant problem for unlicensed devices in terms of access to spectrum. Thus, it is unclear why the Commission believes it is now necessary to enhance the ability of unlicensed devices to access licensed spectrum and at significantly higher power levels. Moreover, any additional spectrum that may be needed for unlicensed devices should come from the less congested bands above 5

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22 *NOI/NPRM* at ¶ 18.

23 In comments being filed today, V-Comm analyzes the consequences for licensed providers of even a slight increase in the overall noise and interference floor due to unlicensed underlays. To maintain current capacity, quality, and coverage, a licensed network operator would have to overbuild its networks very substantially. In V-Comm's estimation, a 3 dB increase in the noise and interference floor would require a national operator to engage in overbuilding that would increase its costs by 390%, using CDMA technology for its analysis. *See* V-Comm Comments at Section VI, Table 7. While the cost increase for a GSM operator such as Cingular would vary, V-Comm's estimate provides an indication of the order of magnitude of how underlaid unlicensed operation will affect the value of licensed spectrum.

GHz, where, as the SPTF recognized, technological advances are increasingly making spectrum capable of being used for new applications and services.[24]

If the Commission believes that use of the IXTemp metric can allow it to cram more unlicensed users into a given bandwidth, it should start with the bands where unlicensed use now prevails. There is no indication that there is any substantial need for unlicensed access to licensed spectrum.

As long as unlicensed access to spectrum is viewed as a free good, there will, of course, be a continuing demand for such access. When unlicensed access to spectrum is made available only at a cost, like licensed spectrum, the demand diminishes considerably.[25] Unlicensed spectrum users, needless to say, face interference and congestion in bands that they can use without cost. That is an example of the "interference and oversaturation . . . resulting in inefficient use"[26] that leads to the "tragedy of the commons."[27] Even though unlicensed use has led to inefficiency and congestion, the Commission appears to believe that unlicensed access to licensed spectrum will not have the same consequences through the magic of IXTemp. Requiring use of the IXTemp metric in the bands currently used by unlicensed devices could improve the efficiency of

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[24] *See SPTF Report* at 19. Manufacturers should be encouraged to focus on technologies that will continue to make better use of frequencies above 5 GHz. Spectrum below 5 GHz is already congested and adding unlicensed operations will only exacerbate the problems faced by incumbent licensees and unlicensed operators. By implementing the interference temperature only above 5 GHz, manufacturers will be incented to focus their development dollars on equipment that would operate on uncongested spectrum, instead of equipment that would operate on congested spectrum below 5 GHz. This would also accelerate the development of equipment and services capable of operating in higher bands. We note, in this connection, that there is already considerable standards work relating to the higher frequencies, including unlicensed use.

[25] The Commission allocated spectrum for "unlicensed PCS" devices in 1994, but required that incumbent users be reimbursed for the cost of relocation. That spectrum has languished almost unused, despite the alleged demand for unlicensed spectrum, and is now being considered for reallocation for licensed use.

[26] *SPTF Report* at 37, 40.

[27] *Id.*; *see generally* Garrett Hardin, *The Tragedy of the Commons,* 162 SCIENCE 1243 (1968).

unlicensed spectrum usage and diminish interference, if the concept actually works, without the risk of impacting adversely the current licensed bands.

Moreover, the nature of unlicensed spectrum usage makes it virtually impossible to recover from a bad decision. Once millions of unlicensed units are in use, there is no way to stop them from being used for many years to come.[28] Without licenses, the units are beyond any effective means of Commission control. The Commission will have no record of who owns the units or where they are being used. As a result, the SPTF recognized the embedded user base will have "squatters' rights" that will continue to diminish the usefulness of the licensed spectrum they share.[29] Thus, even if the Commission were to find the interference from unlicensed users warranted terminating their legal right to access a particular band, it would not be able to rewrite history and actually restore the licensee's right to use its spectrum without interference from unlicensed devices.

The Commission also needs to reexamine the rationale for the supposed paradigm shift with respect to interference protection that the IXTemp metric was intended to facilitate. The Commission asks whether a shift is needed from a model based on transmitter operations towards a model based on receivers and the RF environment.[30] The fact that this question has not yet been answered suggests how inappropriate it is to proceed with a rulemaking to implement this shift at this time.

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[28] This is especially true where the unlicensed devices are used by consumers. Once there is an embedded base of consumer units, many of those units will continue to be used as long as they continue to function, even long after the units are taken off the market, because some consumers will resist upgrading to new units using a different frequency as long as their existing units work, even if the new units have additional features.

[29] *SPTF Report* at 58 ("[O]nce unlicensed devices begin to operate in an easement, it may be difficult legally or politically to shut down their operations even if they begin to cause interference or otherwise limit the licensed user's flexibility. Thus, . . . the potential for 'squatters' rights' issues to arise is another downside of the easement model that must be addressed.")

[30] *NOI/NPRM* at ¶ 8.

More importantly, the fact that the Commission has asked the question in the first place suggests that the Commission has ignored standard engineering practices. In performing any analysis of radio systems and RF interference, all of the characteristics of the various components in the system must be used. This is nothing new in the development and deployment of radio systems.[31]

3. IXTemp Epitomizes Command and Control

Finally, the use of the IXTemp metric will undermine the objective of evolving from a command-and-control regulatory regime to a flexible, market-oriented one, as urged by the SPTF.[32] Facilitating unlicensed "commons" use of occupied, licensed spectrum will require the establishment of "significant regulatory limitations . . . that preclude many other technically and economically feasible spectrum uses that rely on higher-power signal propagation over longer distances, or that require greater protection from interference."[33] The regulatory application of the IXTemp metric to licensed spectrum would involve just the kind of command-and-control regulation that the SPTF urged the Commission to avoid. Noting that the IXTemp-based "easement model inherently limits the flexibility afforded to the licensee to some degree, and relies on

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31 This analysis is usually accomplished by examining the characteristics of the transmitter and receiver. Since the actual physics of propagation, path loss, antenna patterns, etc., must be the same in either "model," there should be no real difference between the two approaches. The analysis can start with assumptions for transmit power, distance, etc., and then calculate the expected receive power for a certain device or, alternatively, the analysis can start with a requirement for receive power or receiver interference and then calculate the expected transmit power for various scenarios. Thus, the analysis can be approached from one direction or the other but the end result should be the same if the same assumptions are used to define the model. Therefore, the change of the Commission's "paradigm" is nothing more than a change in terminology and in and of itself offers nothing new in terms of managing the various users of the spectrum bands. The only thing that is new in this case is that the new buzzword "interference temperature" has been introduced.

32 *See SPTF Report* at 16-19, 21, 24, 35-39.

33 *SPTF Report* at 40.

government to define the scope of the easement,"[34] the SPTF clearly stated that it "does not advocate the wholesale conversion of all spectrum to a commons approach."[35] Use of IXTemp would diminish the flexibility to introduce new, efficient technologies that exists under the current market-oriented flexible-rights regulatory regime for CMRS.

B. Interference Temperature Will Not Benefit Licensees by Providing Greater Certainty Regarding Interference Protection

The *NOI/NPRM* suggests that the use of an IXTemp metric could "be beneficial to licensees" by providing them with "greater certainty" concerning protection from interference.[36] This is not so, at least with respect to those currently holding exclusive licenses. In the case of the bands currently allocated to mobile service, it is unclear why the Commission believes that there is any level of uncertainty or what exactly this uncertainty may be. The limits for out of band emissions and electromagnetic field strength at a border of the licensee's area are well known and understood throughout the CMRS industry. These regulations have worked well for purposes of managing inter/intra-system interference and providing the licensees flexibility in their service offerings and network deployments. On the other hand, the still undefined concept of "interference temperature" introduces significant uncertainty into the interference environment that end users of the mobile service would experience and what IXTemp's overall impact will be on the capacity and quality of tomorrow's wireless networks. If the goal is to provide a greater degree of certainty to these bands, then the Commission should prohibit the use of unlicensed devices within licensed bands. The only "certainty" that the IXTemp metric would bring to CMRS licensees is that others would be using their exclusively licensed spectrum and increasing the noise plus interference floor.

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34 *SPTF Report* at 58.
35 *SPTF Report* at 40.
36 *NOI/NPRM* at ¶ 15.

The solution in this case should be a clear and unambiguous distinction between licensed bands, in which no unlicensed use is allowed, and bands dedicated solely to unlicensed use. This level of clarity and certainty will promote the development of technologies that will have a greater chance for acceptance and success in the market. By adopting an approach where unlicensed devices are not allowed to operate in licensed bands, bidders for licenses assigned through auction can more accurately determine the value of the licenses being auctioned. Similarly, the recent success of unlicensed devices based on 802.11b/g/a is due to the certainty that the 2.4 GHz and 5 GHz unlicensed bands are allocated to these types of devices and the likelihood that products built by different vendors will operate compatibly on the same frequency bands. It is unclear if unlicensed devices that are targeted toward operation in a particular licensed band (*e.g.* 12-13 GHz) will be successful in the marketplace because these devices must accept interference from the licensed users of the band, which would lead to unsatisfactory performance.

C. Mandatory "Underlays" and "Easements" Based on Interference Temperature Will Undermine Licensed Service and Upset Investment-Based Business Plans

An FCC mandate that licensees must share their "exclusive" spectrum would convert an exclusive license into a hybrid license where the licensee's use of the spectrum is limited by the IXTemp metric. This would destroy the premises on which the current exclusive licensees obtained their licenses and on which they have based business plans involving investments of billions of dollars.[37]

It would ensure that the licensee will increasingly face "worst case" interference conditions, and takes away the licensee's ability to avoid or manage such conditions through interference management, use of alternative technologies, and other engineering approaches. Moreover,

[37] *See also* V-Comm Comments at Section VI.

it precludes the licensee from implementing technologies that may improve efficiencies and allow reception of its licensed service at levels where effective communication may not *currently* be possible. In essence, the interference temperature analyzes the "worst-case" scenario for receiver operations under *current* technology and usage conditions and precludes licensees from addressing this scenario as technology evolves.

For example, when CDMA was developed, it allowed licensees to operate at signal levels previously viewed as commercially unattainable (*i.e.*, "below the noise floor"). It effectively lowered the operating point for licensees deploying CDMA technology by displacing analog technology that generated a higher "interference temperature." If an interference temperature had been established based on the previously accepted analog signal levels, it is unlikely that CDMA technology would have ever developed. There would have been no reason to invest in the new technology if interference from unlicensed operations were allowed at such high levels. The existence of a predetermined interference temperature would tend to force licensed users toward the lowest common denominator, thus limiting their spectral efficiency.

The central issues here are that licensees' interference tolerance changes over time, and licensees should be given incentives to use their spectrum *more* efficiently rather than less so. Requiring incumbents to share spectrum with new unlicensed uses, however, has the opposite effect. The Commission should ensure that sharing does not penalize the most innovative and efficient users of radio spectrum. This requires careful attention to the actual noise floors and operating conditions in existing and to-be-deployed radio systems. It also requires the Commission to address the interference protection needs of incumbent licensees who may have a heightened sensitivity to increased noise or interference because (1) they may be providing service today that is optimally engineered through reliance on a combination of the existing noise floor and the use of technologically advanced equipment and careful engineering and management techniques, or (2) they may be relying on the introduction of emerging technologies to achieve greater spectrum efficiency.

This is particularly true with cellular/PCS networks which always operate with noise, external interference, and self-interference, which is generated by the system itself. In general, the self-interference in the network is caused by the combination of in-cell interference and out-of-cell interference. Technologies such as joint detection, multi-user detection, and interference cancellation can effectively remove the self-interference because the statistical characteristics of the signal are well known to the receiving systems in the network (mobile and base). With these advanced technologies, the system will be limited only by the noise and external interference which cannot be removed. If unlicensed operations were allowed at power levels based on the total interference level (including the self-interference), there would not be an incentive to deploy the advanced receiver technologies. For cellular systems, the self-interference should never be used as a guide to set the interference threshold, or temperature, for the spectrum band being used.

Similar types of improvements have been achieved in the past as evidenced in cellular systems today. Over time, mobile and base station receiver noise characteristics have improved, permitting the extension of reliable service over greater distances in rural areas. After some time, the 39 dBμV/m protected service contour adopted in the 1980s no longer adequately depicted the actual service areas of carriers. Accordingly, the Commission changed its criterion to a 32 dBμV/m service area boundary to reflect the fact that carriers were taking advantage of improved equipment and were engineering their systems consistent therewith.[38] Since then, systems have matured further, and low-powered handheld units have become nearly universal, with

[38] *Unserved Areas in the Cellular Service,* CC Docket 90-6, *Second Report and Order,* 7 F.C.C.R. 2449 (1992), *recon. denied,* 8 F.C.C.R. 1363 (1993) (*Unserved Areas*), *aff'd sub nom. Committee for Effective Cellular Rules v. FCC,* 53 F.3d 1309 (D.C. Cir. 1995).

3-watt mobiles becoming rare, thus reducing the signal strength of interfering units. Moreover, handheld units are often used indoors, further decreasing the strength of undesired, interfering signals. The move toward digital service has further lowered the power levels being transmitted at cellular frequencies, thereby reducing prevailing self-interference levels. As a result, the interference level resulting from signals of undesired mobile units has decreased dramatically, causing a reduction in the overall noise plus interference floor at base station receive sites.[39] In addition, the system noise floor has also been reduced by improvements in base station receiver performance, with the noise figure dropping from about 8 dB to about 4 dB, permitting a further reduction of about 4 dB in the received noise floor. These developments permit high-quality service to be extended to units in areas that would have been marginal, at best, a decade ago. If the interference temperature had been established during the period of 3 watt analog phones, cellular licensees would never have been able to improve efficiency by taking advantage of the lowered noise and interference levels in the cellular system.

By operating more efficiently, licensees push their technologies and their spectrum usage closer to the performance limits, which often means that the signal is more sensitive to interfer-

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[39] In a 1997 waiver request, AirCell, Inc. represented that the noise floor in a cellular system was considered to be -107 dBm at an urban cell site, -115 dBm at a suburban cell site, -118 dBm at a rural cell site, and -120 dBm at a "rural quiet" cell site. AirCell, Inc., "Petition, Pursuant to Section 7 of the Act, for a Waiver of the Airborne Cellular Rule, or in the Alternative, For a Declaratory Ruling" (AirCell Petition), Exhibit B, *Analysis of AirCell Flight Test Data and Its Effects on Terrestrial Cellular Operations,* at 7 (filed Oct. 9, 1997). AirCell gave little explanation for the source of these figures, but they were apparently based on information from several cellular systems in the mid-1990s. However, contemporaneous measurements by AirCell's test contractor showed that the figures on which AirCell relied had already become outmoded. The TECC Report attached to its filing showed that the measured noise floor at two rural quiet cell sites was about -127 dBm, 7 dB lower than the -120 dBm figure that supposedly had been based on prior data. *See id.,* Exhibit C, TEC Cellular, Inc., *Final Report: AirCell Flight Test July 10-11, 1997,* at 117-18. Since then, the noise floors of typical rural, suburban, and urban cell sites have been shown to have declined substantially in the AMPS Noise Floor Tests performed by V-Comm, L.L.C. A copy of that test is being submitted with V-Comm's comments in this proceeding.

ence or degradation than a signal in a less sophisticated system. For example, a licensee that pushes the technology to increase capacity or throughput will be more heavily affected than less efficient licensees by FCC decisions that allow an additional source of noise or external interference to affect the spectrum used. Similarly, the noise floor is generally lower in rural areas than in urban areas. Thus, rural wireless systems engineered to take advantage of this fact would be adversely affected by an interference temperature that does not account for their unique operating parameters.

The Commission must recognize that in modern, well engineered cellular/PCS systems, harmful interference will do more than simply disrupt a single phone conversation or a single user. Increased levels of interference will impact not only the call quality or data throughput, but can affect the entire cell and possibly even the network as a whole through a decrease in network capacity and coverage. It is well known in cellular system engineering principles that coverage, quality, and capacity are inter-related and when one is affected then all are affected, thus reducing the overall performance and efficiency of the system.[40]

The Commission must not take steps — such as adopting an ill-formed interference temperature model — that would potentially require licensees to diminish their efficiency or service quality or increase the cost of providing service to their customers.[41] Carriers may be disincented from implementing more efficient technologies if unlicensed operations are allowed further access to their spectrum. Despite claims that unlicensed operations below the interference

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40 *See, e.g., WCDMA for UMS* (Harri Holma and Anti Toskala eds., 2000).

41 The service quality of CMRS carriers is receiving increasing attention at the state and Federal level. Service quality degradation caused by IXTemp may have the additional affect of increasing regulation of CMRS services.

temperature would not cause interference to licensed operations, there is no guarantee, especially in worst case conditions.[42]

D. Technical Critique of the Interference Temperature Concept

"Interference temperature" is not an established scientific or engineering term. It is purely a regulatory creation, announced in the *SPTF Report* and a staff working group report.[43] As a result, there is no accepted definition of the term, nor is there a body of technical literature addressing its derivation and use: The Institute of Electrical and Electronics Engineers does not define or use the term, and it is not found in engineering and technical references or standards.[44] Accordingly, if the IXTemp concept is to be used to define the respective rights and responsibilities of licensees and unlicensed users, it must be rigorously defined and its implications analyzed carefully. To date, this has not occurred. Only a vague concept has been set forth, with indistinct origins, and the Commission has not analyzed its full implications.

1. Inadequate Definition of Interference Temperature

According to the *NOI/NPRM,* the Commission intends the "interference temperature" to represent the total interference in a given bandwidth, as measured in power spectral density ("PSD", in units of Watts/Hz, W/Hz). As a technical basis for this new term, both the SPTF Re-

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42 For example, if the interference temperature for cellular systems were set at -107dBm, based on the early 1990s estimates of urban noise and interference levels, a signal at -110 dBm (3 dB under the interference temperature) could interfere with calls in rural areas or even in certain urban areas where worst-case conditions did not previously exist. *See* AirCell, Inc., Petition, Pursuant to Section 7 of the Act, For a Waiver of the Airborne Cellular Rule, or in the Alternative, For a Declaratory Ruling, Exhibit B – Analysis of AirCell Flight Test Data and Its Effects on Terrestrial Cellular Operations at 7-8 (Oct. 9, 1997).

43 *See SPTF Report* at 27; SPTF, Report of the Interference Protection Working Group at 12-13 (Nov. 12, 2002).

44 *See, e.g.,* John Kraus, ANTENNAS, 2d Ed., McGraw-Hill, 1988; *IEEE Standard Definitions of Terms for Radio Wave Propagation,* IEEE Standard 211-1997, reaffirmed Sept. 11, 2003; *IEEE Standard Definitions of Terms for Antennas,* IEEE Standard 145-1993; *IEEE Standard Test Procedures for Antennas,* IEEE Standard 149-1979, reaffirmed 2003; *American National Standard for Methods of Measurement of Radio-Noise Emissions from Low-Voltage Electrical and Electronic Equipment in the Range of 9 kHz to 40 GHz,* IEEE, 2003.

port and the NOI/NPRM reference only a definition for the term "antenna temperature" (but *not* the term "interference temperature"), taken from a website offering explanations of terms used in modern physics.[45]

The definition of "antenna temperature" currently available on that site consists of only a few equations, lacks any discussion concerning the assumptions used in developing the equations or their general application to specific problems, and employs terms not defined on the page. Moreover, the definition on that site, while appearing complex to the lay reader, is actually incomplete in critical aspects, because it does not include the more fundamental definition of "antenna temperature" used in modern antenna theory, which takes into account the fact that antenna temperature varies based on the directional characteristics of the antenna and the direction the antenna is pointing in relation to the surrounding temperature distribution.[46]

The website relied on by the SPTF and the Commission for the incomplete "antenna temperature" definition on which the entire IXTemp concept is based is neither a peer-reviewed journal nor a widely accepted resource for science and engineering; it is merely an individual's compilation of terms that *may* be used in the discussion of physics. Nothing on this free website indicates that the information is being provided as anything other than a quick reference. This type of limited resource clearly cannot be the underlying foundation for a new paradigm for the FCC's regulatory policies relating to the management of spectrum and interference. At a mini-

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45 *See* Weisstein, Eric W., "Antenna Temperature," <http://scienceworld.wolfram.com/physics/AntennaTemperature.html>, a page from "Eric Weisstein's World of Physics." Dr. Weisstein is the Technical Internet Encyclopedia Developer for Wolfram Research, Inc. (the vendor of *Mathematica* computation software), host of the physics encyclopedia, which is conceded to be a work in progress subject to change without notice. When viewed recently, neither the viewable web page nor its source code contained a creation date or modification date, so it is not possible to determine whether the page currently contains the same information it did in 2002, when it was cited by the SPTF.

46 *See* Appendix A at Equation 7 and accompanying text.

mum, the failure of the formula taken from the website to account for directional variations disqualifies it for use in governing radio services that employ directional antennas extensively.

Ironically, the Commission, after citing the website as its source for the definition of *antenna* temperature, does not apply the formula from that site in its own definition for *interference* temperature.[47] Instead, the Commission simply uses "interference temperature" as equivalent to the total noise and interference power within a given bandwidth (*i.e.,* the power spectral density, PSD), converted from watt-seconds (or watts/Hz) to Kelvin (temperature) for no apparent reason other than to use the less familiar Kelvin units.[48] This expression of PSD (or band-limited noise power) as an "interference temperature" is not the same as the widely used and accepted term, *antenna temperature,* as the Commission seems to believe. For purposes of equating the power spectral density of noise and absolute temperature, this is nothing more than a change of units, since the only difference in the terms is the division of the PSD by a constant, as shown in note

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47 The website defines *antenna temperature* as $T_A = \frac{c^2 B_\nu}{2k\nu^2} = \frac{h\nu / k}{e^{h\nu/(kT)} - 1}$. (As pointed out above, not all of the terms used in the formula are defined on the web page; some of the terms are defined on linked pages, while others are left undefined altogether. There is no indication how the formula is to be used in practice.) The *NOI/NPRM,* on the other hand, defines *interference temperature* as "a measure of the RF power generated by undesired emitters plus noise sources that are present in a receiver system (I+N) per unit of bandwidth," represented by either (a) "the power received by an antenna in watts divided by the associated RF bandwidth in Hertz and . . . Boltzman's [sic] constant" (*k* in the formula above) or (b) "the power flux density (*e.g*., microWatts/m^2 over a bandwidth) multiplied by the antenna capture area in meters squared divided by both the associated RF bandwidth in Hertz and Boltzman's [sic] constant." *NOI/NPRM* at ¶ 10 & n.15. The Commission does not express its definitions in formulas, nor does it attempt either to derive its definitions from the formula on the website it cites or to show any relationship to the formula.

48 The Commission applies $P_{noise} = kTB$, where *k* is Boltzmann's constant (1.38 x 10^{-23} Joules/Kelvin, J/K), T is temperature of the resistor expressed in Kelvin, and B is the bandwidth in Hz. By rearranging the terms, the power spectral density can be written as $PSD = \frac{P_{noise}}{B} = kT$, where PSD is expressed in the familiar units of Watts/Hz. The Commission arrives at T, the interference temperature, as a proxy for PSD by dividing it by *k,* such that $T = \frac{P_{noise}}{kB}$.

48. In this conversion there is no new information provided except for a new mathematical unit (Kelvin), and a similar conversion could be made to convert the power spectral density (W/Hz) to any other acceptable unit, such as horsepower per kilohertz (HP/kHz).

However, more important is the distinction between a general *noise temperature* and *antenna temperature*. While the *noise temperature* at the location of a receiver, which does not take into account the characteristics of the antenna, can be generally thought of as being equivalent to power spectral density of the noise level at that location, the *antenna temperature* is much more complex as it intrinsically depends on the radiation pattern of the antenna, the direction the antenna is pointed, and the distribution of noise sources in relation to the radiation pattern. Thus, the *antenna temperature* depends on the particular antenna, the direction it is pointing, and its environment: these factors cannot be simply de-coupled without the use of several simplifying assumptions which would severely restrict the general applicability of the model. The (properly computed) antenna temperature, therefore, would appear to be a better representation of noise levels at the receive location than noise temperature, for purposes of computing the interference temperature, which the Commission intends to be "a measure of the RF power generated by undesired emitters plus noise sources that are present in a receiver system (I+N) per unit of bandwidth."[49] External sources of noise and interference cannot be quantified as "present in a receiver system" without taking the antenna system characteristics into account. The Commission never fully addresses the fact that its IXTemp metric needs to account for the characteristics of the antenna system employed by any given receiver.

To confuse things even more, the *NOI/NPRM* also refers on several occasions to "interference noise temperature" and "noise temperature" without providing definitions for these terms. In paragraph 23 (first and fourth bullets), it appears to use these terms as equivalent to

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[49] *NOI/NPRM* at ¶ 10.

"interference temperature," without any explanation. In paragraph 33, however, it uses the term "receiver noise temperature" to represent the Kelvin equivalent of the receiver's noise figure, and in the link budget table in Appendix B it uses the term "equivalent satellite link noise temperature" in a similar way.

2. Inadequate Definition of Interference Temperature Density

In addition to the term "interference temperature," the Commission has also attempted to introduce the concept of an "interference temperature density,"[50] which would be measured in units of Kelvin per square meter (K/m^2). As described by the Commission, this quantity is "defined as the interference temperature divided by the effective capture area (aperture) of the receiving antenna." However, as in the case of "interference temperature" above, this concept is not rigorously defined and is seriously flawed, because it does not take into account the directional characteristics of the antenna or the directions from which the interference is coming.[51] Similarly, the effect of the differences between the radiation patterns of two different antennas is more complex than what is suggested by the Commission. It is simply not technically correct to assume that the calculation of an "interference temperature density" could be measured with a particular antenna and would then be "independent of receiving antenna characteristics." This concept is not supported by the fundamental electromagnetic properties of antennas. For example, the interference temperature density resulting from a given source of interference will be greater if it is received from a direction for which the receiving antenna gain is high (and hence

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50 *NOI/NPRM* at ¶ 10 n.15.

51 As shown in Appendix A, the antenna effective aperture is a function of the radiation pattern of the antenna and can vary widely depending on the direction of the incoming power flux density. *See* Appendix A at Equation 1 and surrounding text. Also, as noted above, both the antenna temperature and the received power due to a source of interference can vary depending on the direction the antenna is pointed even when the antenna is located at the same physical location.

the effective aperture is high), and will be less if it is coming from the direction for which the receiving antenna pattern has a null (and the effective aperture is extremely low).

In terms of measurement units, the quantity the Commission is referring to as "interference temperature density" is actually nothing more than power flux density measured in a certain resolution bandwidth, converted from W/m^2 to K/m^2 through simple division by a constant.[52] Thus, in terms of measurement units there is no substantive difference between the power flux density measured in a given resolution bandwidth and the term "interference temperature density" except for the inclusion of Boltzmann's constant and the corresponding change in the measurement units.[53] However, the units of measurement are not what is important in the analysis of wireless systems and interference. As described above, a simple change in the units does not provide any additional information or alter the underlying physical principles involved.[54] Manipulating the units of measurement is not a substitute for sound scientific analysis and engineering. There is no need to attempt to invent new terms because no new information is derived.

3. Relationship Between Interference Temperature and Noise Floor Is Inadequately Explained

At a later point in the document, the Commission again notes that it is necessary to understand "the RF environment, *i.e.,* the noise floor" before "interference temperature" limits can

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52 As shown in Appendix A, Equation 1, the power collected by an antenna due to a discrete source is equal to the product of the power flux density and the effective aperture of the antenna. Rearranging the terms, it is clear that the power flux density (W/m^2) is equal to the power collected by the antenna divided by the effective aperture in the direction of the source: $S = \frac{P_A}{A_e(\theta,\phi)}$. This equation can be extended to account for power spectral density (W/Hz) if both P_A and S are measured over the same resolution bandwidth. In this case, the power flux density, S, would be in terms of $(W/Hz)/m^2$. This is then converted to "interference temperature density," expressed in K/m^2, by dividing by Boltzmann's constant.

53 This is also similar to the unit "Jansky," used in radio astronomy, which is equivalent to $(W/m^2)/Hz$ by application of a constant conversion factor (*i.e.,* 1 Jansky = $1x10^{-26}$ $(W/m^2)/Hz$).

54 We note that the term "interference temperature density," like "interference temperature," does not appear in the engineering and technical references and standards cited in note 44 above.

be used as a tool for managing interference.[55] In the definition proposed by the Commission, the noise environment, represented by N, is composed of "the cumulative environmental RF energy generated by sources external to an operator's receiving equipment," which would include noise generated by "atmospheric conditions, galactic sources, and man-made incidental radiators" — *i.e.,* the sum of thermal and environmental noise. The Commission further clarifies that the value for N does not include the noise figure of the receiving equipment[56] and excludes signals from intentional radiators, which constitute interference, represented by I.

From this explanation, the noise (N) quantity that is described by the Commission is similar to the antenna temperature as defined by Eq. (7) in Appendix A (*i.e.,* thermal noise, as received by a particular antenna) plus any other noise (man-made, atmospheric, etc.) that may be present. However, with this definition it is not clear why the Commission had previously pointed to a definition of *antenna temperature* (which takes only thermal noise into account) as somehow leading to its use of the expression "interference temperature," which is intended to represent both noise (thermal *and* environmental) and interference received by an antenna.

The exact definition of "interference temperature" and how it may relate to antenna temperature, the noise floor, or interference levels remains unclear. At this point, it seems that the Commission is attempting to evaluate interference in a particular spectrum band through the use of various technical terms: (1) a measure of the *antenna temperature* for a certain receiving antenna taken over a certain reference bandwidth, (2) a yet to be determined rigorous engineering definition of "interference temperature" that is somehow related to antenna temperature and noise temperature, and (3) a measure of power spectral density defined within a given reference

55 *NOI/NPRM* at ¶ 24.

56 *NOI/NPRM* at ¶ 24 n.20. The Commission's rationale for excluding receiver noise is that "the level of noise produced by the receiver is not a significant contribution to the noise floor if the level of noise produced by external sources combined with the level of interfering signals is at least 6 to 10 dB greater than the level of the noise produced by the receiver." *Id.*

bandwidth at a particular reference point in a radio receiver. However, in fundamental technical terms the power spectral density within a bandwidth may or may not be the same as the antenna temperature, whether one uses the simplified definition from the website referenced by the FCC or the more complete definition in Equation 7 in Appendix A. The descriptions presented in the *NOI/NPRM* do not represent a meaningful technical definition.

4. Inconsistent Use of Interference Temperature

As discussed above, the *NOI/NPRM* specifically states that IXTemp is intended to represent "the RF power generated by undesired emitters plus noise sources that are present *in a receiver system* (I+N) per unit of bandwidth."[57] For IXTemp to have any utility for purposes of interference protection, the only IXTemp levels of relevance would be those at the victim receiver, taking into account the antenna system employed. The IXTemp level at some other location would have no bearing on what the IXTemp level is at the victim receiver location. The Commission appears to recognize this fact when it says:

> For an interference temperature limit to function effectively on an adaptive or real-time basis, a system would be needed to measure the interference temperature in the band and communicate that information to devices subject to the limit, and a response process would also be needed to restrict the operation of devices so as to maintain the interference temperature at or below the level of the limit.[58]

In other words, every unlicensed device would have to have real-time access to the actual measured IXTemp level within each potential victim receiver. Nevertheless, the *NOI/NPRM* indicates that the Commission is considering a variety of scenarios that would depart from this fundamental requirement.

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57 *NOI/NPRM* at ¶ 10 (emphasis added).

58 *NOI/NPRM* at ¶ 11.

It outlines three scenarios: In the first, each device "would measure the interference temperature at its location and make a transmit/not transmit decision based on this measurement plus the device's own contribution of RF energy."[59] This is, of course, inconsistent with the definition of IXTemp, which is referenced to the victim receiver.

The second scenario "would be for the receive sites of a licensed service to measure the temperature and communicate those measurements to a central site, where the interference temperature profile for the region would be computed."[60] It is unclear what the Commission means by this, because IXTemp has meaning only at the location of a particular receiver. Additionally, what is an "interference temperature profile for the region," and how would unlicensed devices ensure that they do not violate the interference temperature for any given receiver?

The third scenario posited by the Commission is the use of "a grid of monitoring stations that would continuously examine the RF energy levels in specified bands, process that data to derive interference temperatures, and then broadcast that data to subject transmitters on a dedicated frequency."[61] None of these "monitoring stations," however, would be able to derive the *actual* interference temperature for any given victim receiver in real time, because it would not be using the victim receiver's antenna.

This concept also has many other technical issues to overcome. For example, how will the measurement "thermometers" know if they are measuring the power contained in desired signals from licensed transmitters or undesired interfering signals from unlicensed devices? How would this information be accessed by devices that intend to begin transmitting? Similarly, will all devices be required to have GPS receivers so they (and the monitoring stations?) will

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[59] *NOI/NPRM* at ¶ 11.

[60] *Id.*

[61] *Id.*

know their location? It is also unclear how, in fact, the so called "interference thermometers" would actually work in the real world.[62]

A final variation mentioned by the Commission would involve "equip[ping] all transceivers on a network operating with interference temperature 'thermometers' and GPS receivers so that they could measure and transmit temperature data on a real-time basis."[63] It is unclear what this means: If the Commission is suggesting that all unlicensed devices would act as "IX-Temp thermometers" and transmit data to other unlicensed devices, that would not provide useful data about interference temperature *at victim receive sites.* If, instead, the Commission is suggesting that all *licensed* spectrum users' transceivers (base and mobile) should be required to monitor and transmit IXTemp threshold data continuously, so that this information could be used by *unlicensed* devices to determine whether to transmit, this would comport with the definition of IXTemp, but the data transmitted would not be meaningful if the network employs real-time dynamic power control, because the relevant threshold only a few milliseconds later could be entirely different, due to the continuously varying power. Moreover, the real-time transmission of such data would require a new allocation of dedicated spectrum, which would seem to undercut the reason for transmitting the data in the first place.

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62 As described in the preceding section, to evaluate the power (or rather the power spectral density) at any point in space, it is necessary to account for all possible directions of wave propagation and for all possible polarizations of the electromagnetic wave as given in Appendix A, Equation 2. Obviously, since a perfect isotropic antenna is not an option for a realistic interference measurement system, the measurement instrumentation must be developed to accurately measure the various field components, polarizations, and directions of wave travel. Furthermore, while a receiver can calculate the amount of power within a certain bandwidth, it is much more complicated to separate the various signals (intended signals, interfering signals, and noise) to determine which individual signal components are at what power level, propagating in which direction(s) and with what polarization(s). This is complicated further by the wireless propagation channels themselves which may exhibit multipath fading and blockages which may change very rapidly in time and as functions of position. *See* Theodore Rappaport, WIRELESS COMMUNICATIONS, PRINCIPLES AND PRACTICE, Prentice Hall, 1996.

63 *Id.*

In short, the Commission's definition of IXTemp as being something measured at the victim receive site does not appear to be consistent with how IXTemp would be used in real-world wireless systems. It would be absurd for the Commission to allocate dedicated spectrum for the transmission of IXTemp information from each licensed receive location in order to facilitate use of the licensed user's spectrum by an unlicensed device; if there were sufficient spectrum for this, the Commission would be better advised to allocate it for unlicensed use and avoid the IX-Temp issue altogether. Yet without such an allocation, there is no way for an unlicensed device to determine whether its operation will impermissibly violate the IXTemp threshold at any given licensed system's receive location. No mesh network of "IXTemp thermometers," even with spectrum for transmitting their data, can provide the information needed to determine whether a given unlicensed transmission will exceed the IXTemp threshold at any given victim receive location.

3. Interference vs. Noise

If a given unlicensed device makes a reading of the signal level on a given frequency, for purposes of determining whether its operation will violate an IXTemp threshold, it is unclear how the device would determine whether the measurement of power in a particular bandwidth represents only interference and noise or rather the power of an intended signal plus any interference and noise. Said another way, it is unclear how a device would "know" whether the measured power is the intended signal, one or many interfering signals, or noise, or some combination of all of these components.

E. Comments on Specific Issues

In Paragraph 20 of the *NOI/NPRM,* the Commission asks several questions related to the introduction of an "interference temperature" approach in two unspecified frequency bands where it "is more feasible for unlicensed devices to be expanded without causing undue interference to the incumbent licensees." Cingular has the following comments:

Q Is there a general metric that can be used to gauge the success of the introduction of the "interference temperature" devices into a new frequency band?

A At this point it is extremely difficult to suggest a metric since there is no technically meaningful definition for "interference temperature." Of course, one answer is that no incumbent services should be subject to harmful interference. It must be noted that interference may impact a system on several levels that may or may not be readily apparent in terms of bit error rate, for example. As Cingular, Lucent, and others have commented to the SPTF, interference can affect the capacity and quality of wireless systems in several ways.[64]

Q Is there a simple metric that can be used to gauge the effect of these unlicensed devices upon the incumbent services?

A The answer to this is essentially the same as for the preceding question. Without a clear definition of "interference temperature" and how the devices will operate, it is difficult, if not impossible to develop a metric to judge the success of their deployment.

Q Should the introduction of "interference temperature" devices be done in stages to ensure that the incumbent services do not suffer undue interference?

A It is unclear what an "interference temperature" device is. In general, unlicensed devices should be allowed only in bands specifically allocated for unlicensed operation. The allowance for these devices has already occurred in the 5 GHz bands that can now be shared with Federal radar systems. Also, as pointed out earlier, if the IXTemp metric will increase the capability of devices to successfully share spectrum then this can certainly be accomplished within the unlicensed bands.

Q 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?

A The answer is the same as above. The introduction should be limited to unlicensed bands. The new adaptive behavior of these devices should be evaluated in terms of their coexistence with other unlicensed systems and certain Federal radar systems.

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[64] *See* Comments of Cingular, ET Docket 02-135, at 21-24 (Jan. 27, 2003); Reply Comments of Verizon Wireless, ET Docket 02-135, at 7-8, 13-15 (Feb. 28, 2003); Comments of Sprint Corporation, ET Docket 02-135, at 13-14 (Jan. 27, 2003); Comments of BellSouth Corporation at 10, ET Docket 02-135, at 10-11 (Jan. 27, 2003); Comments of Lucent Corporation, ET Docket 02-135, at 2-3 and Annex A (Jan. 27, 2003); *see also* Comments of Lucent Corporation, WT Docket 02-86 (AirCell Extension proceeding), at 10-12 and Appendix A (April 10, 2003).

In Paragraph 21 of the *NOI/NPRM,* the Commission explores other questions relating to "interference temperature," noise, and radio technologies. Many of these issues have been discussed in the preceding sections. These questions and the corresponding answers are below:

Q What elements should the Commission consider in setting temperature limits for different bands and locations? The Task Force suggested that some of the factors to be considered in setting temperature limits for a band include: 1) the extent of current use; 2) the types of services being offered; 3) the types of licensees (for example, public safety); 4) the criticality of services and their susceptibility to interference; 5) the state of development of technology; and 6) the propagation characteristics of the band. We request comment on whether these factors are appropriate as well as whether other criteria also should be addressed.

A Before setting "interference temperature" limits for any band, the Commission must develop a rigorous technical definition of exactly what is meant by the term "interference temperature" and must also define the associated measurement procedures. The Commission should not apply these types of limits to licensed bands, especially those that deliver services to mobile receivers.

Q In addition, commenters should address what, if any, technical factors (*e.g.*, power, field strength at boundary areas, antenna requirements) should be considered in determining the "interference temperature" limits for a given service, frequency band and geographic area.

A Without a clear definition of the term "interference temperature" it is difficult to suggest what factors should be considered. However, all technical factors related to the antennas should be included in any analysis of radio systems (*e.g.*, antenna pattern, gain, beamwidth, efficiency, impedance, polarization).

Q What applications are expected to be filled by unlicensed devices operating under the "interference temperature" metric?

A Since the Commission is asking this question and the answer is not known at this time, it is unclear why the Commission has formed an opinion that more spectrum is needed for unlicensed devices and is proposing new rules in the NPRM. If the Commission creates an opportunity for unlicensed devices to share licensed spectrum, it is likely that devices will be marketed to take advantage of the opportunity, even if they cause devastating effects to the licensed service. Microsoft has pointed out that "[i]nevitably, where there are virtually no rules of the road and anything is possible, some entrepreneur will design a technology that interferes with other technologies — sometimes because it must, sometimes simply because it is cheaper."[65] According to the TAC, an application such as this, known as a "noise bomb," would be a disaster for licensees, whose businesses plans could be destroyed as a result of the Commission permitting unlicensed use of their spectrum; moreover, the likelihood of such a technology coming into play will have a "chilling effect on technology and service development."[66]

Q Should factors not specified by the Commission's rules, such as typical modulation types for a given service, be considered? If so, commenters should identify these factors and the rationale?

A Yes, this information should be included whenever possible. To the extent the Commission is asking about unlicensed devices, there are currently different rules for frequency hopping systems and other spread spectrum systems. These types of issues were also discussed during the development of the Commission's rules for UWB. Moreover, in considering any underlays of unlicensed devices in spectrum currently used for licensed services, the Commission needs to consider not only the modulation types employed in the licensed services, but the use of real-time power control, frequency hopping, and other standards-based technologies employed. The Commission also needs to consider and protect the quality levels that are engineered into licensed systems.

Q How should the factors identified be used to determine interference temperature limits? That is, should each factor be considered equally or are some more important than others? Can an equation be developed that uses the identified factors to calculate a temperature?

A A clear definition of "interference temperature" is needed to answer this question accurately. Similarly, this definition should be the starting point in the development of any other analysis. Absent a reasoned technical definition of interference temperature and how such limits are to be computed and applied, it is impossible to provide meaningful comment.

Q Should all the identified factors be used in all cases? Should some factors only be used in some cases? Commenters should provide detailed explanations for including or excluding specific factors in various analyses.

A A clear definition of "interference temperature" is needed to answer this question accurately.

Q 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?

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65 Letter of Microsoft Corp., ET Docket No. 02-135, at 4 (July 8, 2002).

66 FCC Technological Advisory Council II, Sixth Meeting Report at 14-15 (Sept. 18, 2002).

A To answer this question accurately it is necessary to understand the technical details of the systems that are deployed in the primary and secondary services. In addition to the I+N of the primary service, it may be necessary to understand the S/(I+N) of the primary and the secondary services.

Q Are there minimum receiver performance criteria that should be considered as a reference in setting "interference temperature" limits? If so, how should the specifications for such a reference receiver be developed? Or should the Commission use the worst receiver available for a service, or an average receiver, in determining temperature limits? How would such a receiver be identified?

A In CMRS, the standards typically include the expected radio receiver performance. However, the Commission must realize that if interference limits are put in place based on the current expected performance limitations for receivers then this may actually serve to also limit the development of improved receiver technologies in the future. For example, if a certain receiver had a noise figure of 20 dB and the allowable interference in a band were based on this figure then there would be no incentive for designers to attempt to design a receiver with a noise figure of 10 dB, because the higher noise levels would negate any benefits from an improved noise figure.

Q To what extent should noise and emissions from existing licensed and unlicensed transmitters be a factor in setting "interference temperature" limits? Should the highest current level of I+N be used as a minimum meaningful level for the "interference temperature" limit or some other statistical representation of measured values?

A It is unclear why the Commission is proposing the "highest current level" of I+N as the "minimum meaningful level" for an interference limit. Similarly, it is not clear how these limits would be derived or measured. For example, as discussed in Exhibit A, it is apparent that electromagnetic interference does not simply exist at a particular point in space. The electromagnetic waves that make up interfering signals are traveling through space with a particular direction, polarization, *etc.* The Commission must also recognize that if the current level of interference is assumed to be (I+N) and additional interference is allowed to be equal to this value, then the new level of interference is 3 dB higher than it was previously. This is an unacceptable alternative.

Q What entities should be parties to the process of setting "interference temperature" limits? What process should these entities follow in determining the temperature limit for a specific band (*e.g.*, each entity gets an equal vote, some entities' votes have more weight than others)?

A If the spectrum bands being considered have already been licensed, through auctions or otherwise, to particular entities, then these entities should be involved in adopting interference limits for these bands. However, since the auctions in this case would have preceded this change of rules being considered by the Commission, there should be no increase in the amount of interference allowed in these bands.

Q Should the Commission allow private agreements between licensed and unlicensed users to set interference temperature limits for specific bands and frequencies? If so, are there incentives the Commission could/should provide to licensees to increase the temperature limit over that set by the Commission?

A If a particular holder of a license decides to allow "underlay" operations at a certain power level then these operations may be allowed provided that it does not cause additional interference to other licensees in adjacent bands or in adjacent geographic areas. This is the only scenario in which sharing should be allowed in licensed bands.

Q How often should "interference temperature" limits be reviewed?

A As the SPTF, the TAC, and others have recommended, the Commission should begin by studying the noise and interference levels in the environment. It is premature to specify a certain time frame at this point. Similarly, it is premature to move forward with new regulations until the underlying research and analysis are completed.

Q What processes should the Commission establish for modifying "interference temperature" limits? In such cases, what criteria should the Commission consider, how should it weigh those criteria, and who should be parties to modification processes?

A If this type of operation is allowed in licensed bands, then the existing licensees must be allowed to actively participate in the discussions of modifications.

Q Are there some services or bands for which the Commission should continue to use the current interference protection procedures?

A At this point, it is unclear how the "interference temperature" metric would be employed to manage interference and how it would be measured or enforced. Until a more rigorous definition is developed, the current procedure should be used in all licensed bands, in particular those bands where services are provided to mobile users.

In paragraph 22 of the *NOI/NPRM,* the Commission asks for comment on several issues related to the possible approaches for measuring and monitoring interference. These questions and the corresponding responses are provided below:

Q How should the Commission decide on the type of "interference temperature" monitoring to be required to provide real-time interference control? Commenters should identify the costs and benefits of the three monitoring approaches discussed above and how they relate to different services. Commenters are also encouraged to identify other monitoring approaches.

A Before deciding on an approach for an interference monitoring system, the overall validity of all of the approaches must be assessed. This is similar to what has been suggested by the FCC's TAC regarding an overall study of the noise and interference environment. Without a clear definition of exactly what "interference temperature" is, it is impossible to determine the requirement for a measurement system or which measurement techniques are appropriate.

Q Should certain monitoring schemes be specified for certain services? Or should this be solely up to the incumbent licensees?

A Different frequency bands may require different solutions. If this is intended to be deployed in licensed bands, the licensees must have direct input of the methods used.

Q How would monitoring systems be funded and who would be responsible for their establishment, operation, and maintenance? Commenters should consider vendors or operators of unlicensed devices and network services, users of such equipment and services, and perhaps licensees.

A In terms of allowing unlicensed devices the use of licensed spectrum bands, the vendors and users of the unlicensed devices should bear the cost burden of any monitoring system and the communications infrastructure needed to make the monitoring system work. The licensed users of the spectrum already bear the (significant) cost of the licenses themselves as well as the other Federal mandates applied to licensed services and technologies.

Q What principles/criteria would be used to choose the location of monitoring sites?

A Based on the definition of IXTemp, the actual receive locations would have to be the monitoring sites, in order to determine the actual IXTemp at the receiver, taking into account antenna characteristics. If the definition of IXTemp is changed, and other monitoring sites are to be used, they must be located in close proximity to the licensed users of the spectrum and must be able to account for various directions of wave propagation, polarization, etc. Furthermore, the Commission must establish the scenarios and provide technical analysis that will prove that such interference monitoring will provide technically meaningful results. At this point, there is no guarantee that the proposed monitoring systems will actually work as envisioned to provide meaningful data. Other than the SPTF Report and this NOI/NPRM, there is no supporting documentation or research results that suggest that this conclusion is correct. Thus, the Commission is moving in a direction based only on an untested assumption and this assumption may prove to be incorrect.

Q How often should the spectrum be monitored? How large a band should be monitored? How should monitoring differ with the type of incumbent services present in a band? What bandwidth should be used for monitoring (*e.g.*, should measurements be taken with a resolution bandwidth of 1 MHz)?

A Depending on the frequency band and how it is used, signal levels can fluctuate by many tens of dBs due to fading and other factors in wireless propagation channels. To provide accurate and meaningful information, any measurement system must measure the channel with a sufficiently small time resolution (perhaps as small as micro-seconds). Similarly, a monitoring system must use sufficient frequency resolution to yield meaningful results. At a minimum, the system should be capable of measuring a resolution bandwidth that is similar to the channel size used by the licensed users of the spectrum. Also, as mentioned previously, the measurement instrumentation must be able to estimate the levels of desired signals, undesired interfering signals, and noise.

Q What detection functions (*e.g.,* root mean squared (RMS), peak or average) should be applied in performing noise measurements? What integration or averaging time should be employed with these measurements? What measurement bandwidths are appropriate?

A The Commission should clarify these points for all wireless services, both licensed and unlicensed. Answers are similar to the foregoing questions.

Q How would the information from monitoring sites be used to determine real-time "interference temperature" values for a specific band in a given geographic area and whether established limits were exceeded?

A It is unclear how an "interference temperature" monitoring system will actually work in the real world to give meaningful results. This issue must be resolved before the Commission moves forward with new regulations. Without a clear understanding of how the measurements will be conducted and how the results will be used, the adoption of any rules is completely premature and the rules will be ultimately unenforceable. The result will be increased confusion in the industry rather than increased clarity.

Q What spectrum resources should be used to convey monitored temperature information to devices subject to temperature limits? Should dedicated frequencies be used for this purpose?

A It is unclear how this type of communication would be achieved without some sort of standard communication protocol that would be required to be included within all devices. The Commission must also develop rules which govern how the devices behave if they do not receive any of the instructions from the monitoring system information.

In paragraph 23 the Commission asks several questions related to device behavior and the sensory and control equipment needed to govern devices when an interference limit is exceeded. These questions and the responses are given below:

Q What response should a device take if it determines that exceeding an established interference noise temperature limit; for example, change frequency, reduce power or place itself in a stand-by mode? Should this response be different if the offending device is a stand-alone device or a device designed to respond to a monitoring system?

A It is assumed that by "interference noise temperature limit," the Commission meant "interference temperature limit," as defined (inadequately) elsewhere. The Commission must determine how a device will know, based on a simple measurement of power in a specific bandwidth, whether the measurement represents noise and/or interference in the bandwidth or rather does it actually represent the power from another unlicensed device or from the primary (*i.e.,* licensed) user of the band. As a conservative approach, if the device senses power in a certain bandwidth it should not begin transmitting and should change to a different frequency. However, there are still many open issues with this approach. For example, how will the device know if another receiver that is near it is actually receiving a signal or not? This is especially true in systems using frequency division duplexing (FDD) since the FDD receiver would actually transmit on a different frequency that the unlicensed device would not detect. Also, it is unclear how a device will be able to determine if its transmissions will actually interfere with other transmissions to a separate receiver. Will the Commission specify the required measurement sensitivity and accuracy of unlicensed devices?

Q Should a graduated response system be used (*i.e.,* should a device iteratively take measures to bring the interference temperature back into the compliant range or should the strongest measures be taken first)?

A This will depend on the services and communications protocols being used in the particular band. As a conservative approach, if a device detects that a particular frequency is being used, it should cease transmissions and move to another frequency.

Q If many devices are operating, is it possible to assign responsibility to specific devices if the temperature limit is exceeded and have those devices take measures to ensure that the temperature is brought back to a compliant level?

A This is one of the many fundamental problems with the entire "interference temperature" approach. The physical principles of electromagnetic wave propagation do not support the Commission's belief that a remote monitoring system will actually work, except where many simplifying (and unwarranted) assumptions are used to contain the problem to specific limited cases. Until these fundamental technical issues are resolved, the Commission should not move forward with this approach.

Q Once an offending device takes measures to bring the "temperature" back to a compliant level, what protocols should be used to determine when that device may resume operating?

A It is unclear how a device will know if its mitigation measures have actually changed the level of interference to make it compliant. For example, how will the device know if another receiver located nearby is still experiencing interference, or not?

Q How should noise temperature limits be enforced? Has technology progressed to the level that the limits could be self-enforced by the radio emitters?

A It is assumed that the Commission actually meant to use the term "interference temperature" in this question rather than "noise temperature". As this apparent mistake indicates, and as described above, there are still many fundamental problems with the "interference temperature" approach that the Commission is attempting to develop. Referring to "noise temperature" would presumably exclude the interference caused by other radio transmitters. However, in terms of limits on interference, the Commission must only move forward if a clear definition of "interference temperature" is developed along with a clear understanding of how it would be measured and eventually enforced.

Today, the FCC can, and will, over an extended period of time, padlock offending facilities that create harmful interference. But the process usually takes years. BellSouth's recent experience with SDARS suggests that the process is neither quick nor easily enforced. Consider the scenario of a large convention center served by several licensed carriers and a large number of unlicensed "underlay" users at the center. In this scenario it is probable that the temperature limit would be exceeded, for whatever reason, even with advanced technology on and operating in unlicensed devices. *Given that the limit is exceeded, and that the licensed carrier(s) experiences harmful interference:*

1. How would the FCC determine *in real time, or close to it,* that the interference temperature limit had been exceeded? Would a portable measuring device be required? Who would pay for its installation and operation? Who would pay the convention center for floor space — or would the FCC require the convention center to provide suitable space at no cost to the government?

2. What actions would the FCC be willing to take in a timely manner to reduce the interference to an acceptable level? *I.e.,* is the FCC prepared and willing to act on the day of the interference report , or would the Commission require several months of proceedings before taking enforcement action to reduce interference at a convention that lasts three days?

3. How would the enforcement work? Would the Commission identify individual unlicensed users in the area and compel them to turn their equipment off or would the carriers be required/allowed to select those to be turned off? How would the Commission select those users to be turned off; and if the carriers can enforce turnoff,

> would the carriers be able to use their own criteria? How would the Commission enforce turnoff? Does the FCC have the ability, legally and practically, to enforce a turnoff requirement, and would it have access to sufficient enforcement personnel to do so in a timely manner? Are federal marshals available to arrest and incarcerate those who refuse to comply? If the carriers are given the authority to select those entities to be turned off, what enforcement rights do they have?

F. Measurements of Noise Floor

The Commission has asked for comments on how to measure the noise floor and how noise levels vary over time, geography, *etc.* As noted above, Cingular and other carriers have addressed this issue with respect to both the cellular and PCS bands by contracting with V-Comm, LLC, which has submitted noise floor studies for both bands for the record in this proceeding.[67] Furthermore, as referenced above, there are already many standards for these types of measurements that have been developed within groups such as the IEEE. There have also been several research studies undertaken by the National Telecommunications and Information Administration ("NTIA").[68] It is unclear why the Commission has not made use of these widely accepted industry standards or the results of research studies conducted by labs operated by the Federal Government. The Commission should explain why these standards and documented results are unrelated to its concept of "interference temperature." Since the SPTF and the TAC have recommended studies and analysis of the RF environment and the noise floor, it may be possible that the NTIA could continue with its research and report its results to the FCC.

The Commission seeks comment on the definition of harmful interference and whether or not a modest rise in the noise floor would not cause harmful interference. As the Commission

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67 *See* page 4 above.

68 *See* NTIA Report 02-390, Man-Made Noise Power Measurements at VHF and UHF Frequencies; NTIA Report 97-336, Broadband Spectrum Survey at Los Angeles, California; NTIA Report 95-321, Broadband Spectrum Survey at Denver, Colorado; NTIA Report 96-330, The Natural and Man-Made Noise Environment in the PCS Bands.

has suggested, most wireless systems incorporate some margin to overcome signal fading. However, in cases where fading is evident on the link, the margin is necessary to overcome the reduced signal power which is caused by the fading process. This is especially true for mobile wireless systems which typically exhibit multipath, or Rayleigh, fading. Similarly, microwave links and satellite links may experience fading due to rainfall, atmospheric effects, or vegetation. It appears that what the Commission now intends to do is to use this margin to allow greater interference into licensed bands.

The effect of this proposed approach is that the performance margin that was designed into the system will no longer be available when it is needed. For example, if a microwave link has been built with a 10 dB margin to account for fading due to rainfall and the Commission then allows the interference in the band to "fill up" this margin with co-channel interference then the margin is effectively gone. During the next rainfall event, the system will have no margin left to overcome the fading and will experience harmful interference. The same sort of analysis may be used in mobile wireless links. If the system is built with a 5 dB margin to overcome fading, then it has been assumed in the system design that the noise and interference are at a certain level which translates into a required signal to noise plus interference ratio. From these performance metrics, the required margin is added into the design to overcome fading. Thus, a system that is designed for a certain performance criteria and with a certain margin will not perform as expected if the interference plus noise level is moved to a higher point thus removing the available margin. In terms of modern mobile radio systems, if the noise plus interference rises then the system will simply not perform as expected in terms of coverage, capacity, and quality of service. Furthermore, this is not sound engineering design. If a system is designed with a certain margin to have some guarantee of acceptable service, it is completely inappropriate to then remove the margin by allowing increased levels of interference.

The net effect of increasing the noise and interference floor even by a small amount is that the performance of networks that are designed with the current noise and interference floor in mind will suffer. If the increase is sustained, these networks will have to be overbuilt to continue providing their current levels of quality, capacity, and coverage, at considerable cost.[69] *Any* such increase in the noise and interference floor would constitute harmful interference.

In paragraph 28 of the *NOI/NPRM,* the Commission poses several questions related to interference. These questions and the responses are listed below:

Q For a given service in a given frequency band, how much interference can be tolerated before it is considered harmful? If the determination of harmful interference would be based on specific quality of service levels, we request comment on the rationale used to justify the recommended constraints. The commenting parties should note the specific frequency bands and services to which their comments apply.

A This is difficult to determine for mobile wireless systems, because the signal levels are rapidly varying due to multipath fading and shadowing. Also, most of the CMRS systems in use are based on industry standards which specify a required signal to noise plus interference ratio to yield an acceptable quality level for voice services. In this regard, any increase in interference which degrades the voice quality below standard levels (*i.e.,* the levels the system is engineered to provide in the absence of the interfering signal) should be considered harmful. Likewise, any increase in interference which degrades data transmission quality, bandwidth, or reliability below standard levels (*i.e.,* the levels the system is engineered to provide in the absence of the interfering signal) should be considered harmful. *Any* short-term increase in the noise plus interference floor due to additional interference will cause a diminution of quality, coverage, capacity, or data speed, which is harmful. If such increases due to additional interference are sustained over the long term, causing the noise plus interference floor to be raised above the preexisting floor, the system's performance will be adversely affected to the extent that the system will have to be reengineered in order to restore quality, coverage, capacity, and data speeds to prior levels, if such restoration is even possible in light of the increased noise plus interference level. In a complex network such as today's cellular and PCS networks, where extensive power control and error correction is employed, harmful interference is not manifested only when all of the system's corrective mechanisms are overcome and calls are dropped; harmful interference occurs when system performance is im-

[69] *See* V-Comm Comments at Section VI.

paired because these corrective mechanisms are needed to maintain quality levels that previously did not require correction and the headroom to maintain quality, coverage, capacity, and data speeds in marginal conditions is diminished.

Q When performing interference studies, what assumptions should be made regarding operating scenarios? For example, commenters should address the duty cycle to be assumed for the desired and undesired transmitters. What assumptions should be made about whether and/or what percentage of antennas might be aligned under typical operating conditions such that there is main beam coupling between undesired transmitters and desired receivers?

A The Commission should use assumptions that are as close to real world operating conditions as possible. This is an area that the Commission needs to study. In some cases (*e.g.,* UWB) the Commission decided that using average power was an acceptable method and this did not specifically account for the effects of duty cycle. In terms of the alignment of antennas, in most cases this will be service specific and the Commission should gather data for each service before proceeding.

Q Can interference from a transmitter be distinguished from naturally occurring noise?

A This depends on the characteristics of the interference and of the receiving system being used. In some instances, an interfering signal will look like random noise to the demodulator within another, unintended, receiver. However, in other instances interference will not appear as "white noise" and can have a much more severe impact on system performance. This is especially true when the characteristics of the interfering signal are similar to the characteristics of the desired signal.

Q Can a statistical approach to developing temperature limits be developed? If so, what parameters need to be developed? How would such an approach be applied?

A This approach might work for some limited scenarios and with some systems. However, this should not be pursued as a general approach to interference management. Of course, if this type of approach is used the end results will depend on the initial assumptions used in the development of the statistical models. Thus, the Commission should clearly define the assumptions to be used in this type of development but only after rigorous study and analysis of real world interference environments across multiple frequency bands.

Q Should the interference temperature limit be set at a level that quantifies "harmful interference" or some other benchmark, or "safe-harbor" level that would constitute less than harmful interference?

A As described above, most wireless systems will attempt to overcome interference by increasing the transmit power. Thus, this will result in even more interference if systems are required to operate when subjected to harmful interference brought about by interference levels that are overly

> lenient. If the margins that have been built into wireless systems are used to accommodate additional external interference the systems will have no other way to provide acceptable performance other than to increase power when possible. In cases where increasing power is not an option, the performance of the system will suffer.

As Cingular and others have commented previously to the Commission,[70] technologies are being developed that can reduce the effects of self-interference caused by the wireless networks themselves. These technologies include multi-user detection, joint detection and interference cancellation. However, these technologies cannot, in general, remove external interference. Thus, the limiting factor will become the amount of external noise and interference that is present within the band. Without *a priori* knowledge of the signal characteristics of the external interference, it will be unlikely that the external interference can be removed in real time as would be required. Also, it is clear that the Commission is attempting to begin the process of allowing higher levels of interference into all spectrum bands, including licensed bands. Over time, this either will limit the abilities of radio systems as they must use more and more overhead in terms of channel capacity to overcome the interference or will cause the users of the spectrum to use ever increasing levels of power. As more power is used, interference will again increase and this process will begin again. Rather than promoting this as a way to increase access to spectrum, the Commission should attempt to prevent this type of cyclical behavior from beginning in the first place. At this point in time, the only logical place for this type of experiment is in bands that are specifically assigned to unlicensed use.

G. A Cost/Benefit Analysis of IXTemp Must be Performed

Cingular has previously noted in its SPTF Comments that the IXTemp model undermines exclusive licensing and discourages innovation. IXTemp ensures that the licensee will increasingly face "worse case" interference conditions, taking away the licensee's ability to avoid or

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[70] *See* note 64, *supra*.

manage such conditions through interference management, use of alternative technologies, and other engineering approaches. Moreover, IXTemp will preclude the licensee from implementing technologies that may improve efficiencies and allow reception of its licensed service at levels where effective communication may not currently be possible. In essence, the interference temperature analyzes the "worst-case" scenario for receiver operations under *current* technology and usage conditions and precludes licensees from addressing this scenario as technology evolves. In short, the IXTemp may actually block the realization of larger long-term efficiency gains.

From an economic perspective, the important issue is whether the net benefits of introducing IXTemp is greater than any associated costs. Here, the benefits are largely speculative — there has been no quantification of these benefits. Indeed, as pointed out in Section I.E above, the Commission is unsure what applications are expected to be filled by unlicensed devices operating under the IXTemp metric. Yet, the costs are fairly well known, if not quantified. IXTemp in the CMRS bands would have a direct impact on the 150 million subscribers of CMRS as well as the substantial investment by CMRS providers. Public-good benefits of CMRS would also be put at risk, including increased productivity from using these products, improved communications, wireless broadband services, services to rural areas, and public safety benefits. As such, even a relatively small service degradation can carry large adverse consequences. Therefore, IXTemp poses an economic tradeoff between known goods and services, highly valued by the consumers and producers who utilize them, and a speculative set of goods and services, whose identity is unknown and whose economic value and successful realization are unknown.

II. COMMENTS IN RESPONSE TO NOTICE OF PROPOSED RULEMAKING

A. It Is Not Appropriate to Proceed with Rulemaking Now

According to the Commission, it will take a significant amount of time to develop the analysis and policies needed to fully implement its concept of an "interference temperature." In spite of this, however, the Commission intends to begin developing new rules to allow greater unlicensed use of licensed frequency bands. The Commission's first step in this approach would be "to establish an interference temperature or equivalent metric" that would allow unlicensed devices to use the spectrum without exceeding the necessary operating margin assumed to be used in the licensed service. To reduce the likelihood of interference to licensed services, the Commission intends to limit the output power of the unlicensed transmitter and require the use of dynamic frequency selection (DFS) and transmit power control (TPC). Other suggestions to control the amount of interference to the licensed service include limiting the number of unlicensed devices or limiting the duty cycle of the unlicensed transmitters.

The Commission is attempting to move forward with new rules even though it acknowledges that more analysis and research are needed. These points have been made repeatedly by the SPTF and the TAC, as well as by many of the parties filing comments on the SPTF report and in other proceedings. Rather than bringing greater clarity to the process of spectrum and interference management, the Commission is doing the opposite — making spectrum and interference management less predictable and less reasoned.

As described in Section I.D, there is no clear definition for the term "interference temperature." This is not an accepted term of art in the wireless industry or in engineering disciplines. Thus, the Commission's invocation of "interference temperature" is nothing more than a "buzz word" and has served to confuse the relevant technical and regulatory issues

As an initial step, the Commission is proposing to "apply the new interference temperature approach" (whatever that might be) to allow unlicensed operation within the fixed service (FS) and fixed satellite service (FSS) band at 6.525-6.700 GHz and the FS, FSS, and broadcast auxiliary service (BAS/CARS) band at 12.75-13.25 GHz with the exclusion of 13.15-13.2125 GHz. It should be noted that the 13.15-13.2125 GHz band has been excluded in this case since it is allocated primarily to mobile BAS/CARS operation. Also, regarding the general applicability of these bands, it is preferable to do this type of experiment in a band allocated to unlicensed service rather than risk interfering with licensed services, as discussed below.

Here the Commission again describes the concept of "interference temperature" in terms of "a measure of the RF power generated by undesired emitters plus noise sources that are [sic] present at the input of a receiver system (I+N) per unit of bandwidth."[71] From this definition it seems that the Commission is using the terms noise (N) and interference (I) to represent the total noise and interference in a certain bandwidth. Thus, the noise (N) is equivalent to the antenna temperature (as defined by Equation 7, in Appendix A) and measured within a given bandwidth. Following this premise, the interference (I) is equivalent to the total amount of power due to interfering signals that is captured by the receiving antenna as measured over the same bandwidth. Using these definitions, it is unclear why the Commission has proposed another new unit, "interference temperature density," which relies on the "interference temperature" and the antenna's effective aperture. Since the antenna temperature and the total interference power depend on the integration over the entire effective aperture and radiation pattern, respectively, it is technically incorrect to then divide by a single effective aperture value as the Commission describes. If the Commission intends to use total values for its analysis then it must be consistent in how the

[71] *NOI/NPRM* at ¶ 33.

terms are mathematically manipulated to ensure that the equations used remain a valid mathematical model for the scenario under consideration.

The Commission briefly discusses the incumbent users within the two proposed bands and the reasons why it believes that these users can withstand additional interference. According to the Commission, the 6525-6700 MHz band is primarily used by FS operations. However, the Commission notes that part of this band, 6650-6675.2 MHz, is used for radio astronomy. It is unclear why the Commission believes that additional interference will have no effect on passive services such as radio astronomy.

It should also be noted in this case that the services in this band will also have to deal with additional interference from ultra-wideband (UWB) devices that were recently approved by the Commission. This raises another issue related to unlicensed use of licensed bands: in the analysis of various interference scenarios the Commission must account for all types of unlicensed devices which could be operating in a particular band. Thus, there may be devices that are built specifically for a particular band but there may be other radiators, such as UWB devices, that have the capability to cause interference in the particular band as well. As the Commission also has noted, unlicensed operation is already allowed in these bands. This has been the case within the general Part 15 regulations for some time and has been made more evident by the recent approval of UWB transmitters. However, it is unclear why there is a need at this time to increase the allowed transmit power levels for devices operating in these bands. At this point in time, there have been very few UWB devices deployed; however, the proponents of the UWB industry have suggested that millions of UWB radios will eventually be on the market. Thus, it is too soon to tell how much of an adverse effect the deployment of UWB transmitters will have on other services including licensed services.

According to the Commission,[72] the current rules for unlicensed devices restrict the transmit EIRP to -41.25 dBm, whereas the licensed services (FS, FSS, BAS) typically operate in the neighborhood of 85 dBm. The Commission explains that in its "sound engineering judgment" the difference between the allowed transmit power levels (*i.e.*, 126.25 dB) intuitively supports the conclusion that expanded unlicensed operation should be permitted. With digital microwaves, however, typical EIRP levels range from 60 dBm to 75 dBm based on a typical 0.5 watt to 2 watt transmitter and 6 to 8 foot standard performance dish antennas. When computing interference, the interfering path must be below the "interference objective" for the victim microwave link. For the typical path shown in Appendix B, the interference objective is –114.5 dBm which yields an interference margin of 21.5 dB and not the 126 dB as depicted by the Commission.[73]

Digital microwave paths are designed to meet a desired performance. The components that make up this performance are its composite fade margin (CFM) and its threshold to interference (T/I) margin. The CFM is defined as the ratio between the receivers' dynamic sensitivity (10^{-3} BER) threshold and the unfaded carrier signal level. The T/I parameter is a measure of the ratio between the receivers' static sensitivity (10^{-6} BER) threshold and the level of total interference.

It is this T/I threshold, not the composite fade margin, which defines the maximum level of interference for acceptable BER performance of the link. For well designed microwave paths below 8 GHz, the predominate fading mechanism is Rayleigh fading. The use of the traditional analog flat fade margin can no longer be used to predict outages for digital microwave links. The main source of interference is inter-symbol interference resulting from the varying degrees

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72 *See NOI/NPRM* at ¶ 37.

73 *See* Appendix B, response to paragraph 37.

of differential delay introduced across the base-band. This delay is a product of a Rayleigh fade, and therefore, has nothing to do with the unfaded received signal level. As can be seen, this "intuitive" approach is meaningless and incorrect. Therefore, before reaching a conclusion it is necessary to analyze the deployment scenarios in more detail and with quantified assumptions that actually represent the operation of real systems. A simple difference in transmit EIRP is not enough information to reach this conclusion without understanding more about the possible FS link budgets involved and the expected number of unlicensed devices.

The microwave band is split into two segments: 6525 MHz to 6700 MHz (transmit low) and 6700 MHz to 6875 MHz (transmit high). The stations along a typical microwave route alternate between transmit low and transmit high frequencies. This NPRM is only addressing the lower half of the band which means that the transmit and receive frequencies of the unlicensed device will both be in the same microwave band segment. Therefore, the signal being received by the unlicensed device will be coming from the distant end of the microwave link as shown in Figure 1 below. If the unlicensed receiver can't hear the microwave signal, it may try to key on noise bursts, or worse, on signals from other unlicensed devices that could result in an overly high transmitted level and a case of interference into the victim microwave receiver. As stated above, the unlicensed device may never hear the distant microwave transmitter. At best, receiver C will see the distant transmitter A at a level of –114 dBm. [74]

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[74] *See* Appendix B response to paragraphs 43,44 and 45.

Victim Microwave Link

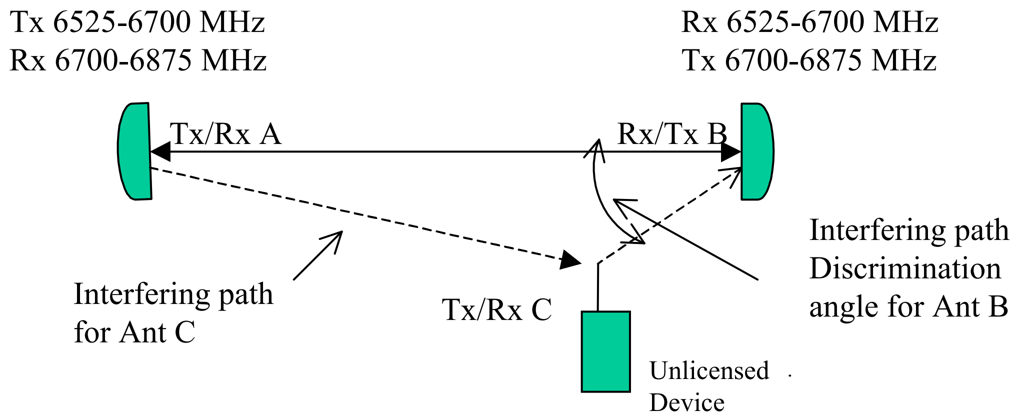

Figure 1

As the Commission correctly notes, there may also be differences in the numbers that have been presented due to the use of different bandwidths and other factors.[75]

A detailed critique of the interference potential of using interference temperature as a metric for permitting unlicensed use within the FS spectrum as set forth in the *NPRM* is set forth in Appendix B: Critique of the NPRM.

For spectrum sharing in bands that include FSS the Commission has proposed an interference criterion of ΔT/T of 6%. According to the Commission,[76] this value has been used in the past by the ITU although no clear reference to an ITU document is provided. The Commission also refers to this value as "the typical receiver noise temperature,"[77] but it is unclear from this description whether this includes the noise component within the receiver or not.

Moreover, the Commission explains that the increase in noise, ΔT/T, is defined as an "increase in system noise temperature and corresponds to the interference-to-noise ratio, I/N."[78] In this case, since the term "system noise temperature" is used, it is generally assumed in the analy-

[75] *See NOI/NPRM* at ¶ 37 n.34.
[76] *See NOI/NPRM* at ¶ 33 n.24.
[77] *See NOI/NPRM* at ¶ 33.
[78] *Id.* at ¶38 n.36.

sis of radio systems that this does include the noise figure of the receiver as well as any other components that comprise the entire transmitter/receiver system. Thus, this new definition for "interference temperature" seems to be based on an analysis of the entire receiving system and is completely inconsistent from what had been described earlier in terms of the noise component, N, which would be "defined as the cumulative environmental RF energy that is generated by sources external to an operator's receiving equipment."[79] Thus, in the Commission's previous definition the noise, N, would not include the contribution of noise from the components within the receiving system itself. Here again, the Commission is confusing the various terms relating to noise and interference and this serves to further confuse the analysis. Using the definition for noise, N, from paragraph 24 it is unclear why the analysis is based on "system noise" at all.

The analysis also shows that if the Commission's more conservative $\Delta T/T$ value of 5% is used as being equivalent to I/N then this would provide a cap to the amount of interference in the band to be 13 dB below the typical thermal noise level. This raises yet another issue with the Commission's analysis. Since the noise component, N, is defined *not* to include the noise generated within the receiving system, then using a $\Delta T/T$ of 5% requires that the interference must be kept 13 dB below the level of the *antenna* temperature, *not* the *system* temperature as indicated. Here again, there is confusion regarding the various definitions proposed for "interference temperature." Furthermore, it remains unclear as to what recourse would be left to the satellite operators if the unlicensed devices were found to significantly interfere with the satellite link. Certainly, it would likely be impossible to make changes to the satellite receiver in space or recall millions of unlicensed devices from the market.

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79 *See, e.g., NOI/NPRM* at ¶ 24.

The Commission also is considering satellite based receivers for the monitoring of interference and spectrum occupancy.[80] As suggested by the Commission, it may be possible for satellite receivers to monitor $\Delta T/T$, I/N, C/I, C/(N+I), and I, but it is unclear how the satellite receiver would measure these parameters and report results or how this information would be transferred or used by any unlicensed transmitters located on the ground. As mentioned previously, it is extremely difficult for a receiver to determine the amount of power due to each source when receiving signals from the intended transmitter and interfering sources simultaneously.

The Commission also attempts to extend the concept and suggests that this information collected by satellite receivers could also be used by unlicensed devices to "adjust their operation to ensure that they do not interfere with other licensed operations."[81] According to the Commission, it is believed that this type of operation is feasible since satellites have been used for other remote sensing applications that monitor geophysical and environmental conditions on the earth's surface. This concept, as described by the Commission, is completely flawed and technically incorrect. While space-borne radiometers have been used to measure environmental and geophysical parameters, these examples have absolutely nothing to do with measuring interference between transmitters and receivers that are located on the earth. The simple fact that many terrestrial systems utilize directive antennas that are not pointed towards the sky or towards any geosynchronous satellites would make this type of remote sensing extremely difficult and expensive, if not totally impossible. Here again there seems to be some confusion on the part of the Commission in terms of how *antenna temperature* can be measured and used to infer the properties of whatever material is within the main beam of the antenna and how interference may occur between various transmitters and receivers located on the surface of the Earth.

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80 *See NOI/NPRM* at ¶ 50.

81 *NOI/NPRM* at ¶ 50.

According to the Commission, spectrum sharing between unlicensed devices and licensed, terrestrial FS systems can be accomplished through the use of dynamic frequency selection (DFS).[82] Similar to the assumptions for the FSS, the Commission bases its analysis on the use of high-gain antennas on each end of the licensed radio link and the expected path loss between the licensed receiver and the unlicensed transmitter(s). However, it seems quite possible that an unlicensed device could be much closer to a licensed receiver than the Commission suggests. It is unclear why the Commission believes that the distance between unlicensed devices and the licensed receive antenna will be "relatively large, perhaps on the order of one hundred meters or more," but the same scenario is then described with the unlicensed devices assumed to be "close-proximity, ground-based."[83] Also, the unlicensed device will have no way to know whether it is close to a licensed receiver or not. While the Commission believes that its assumptions are conservative and representative of the worst case, there is no supporting documentation or references to support these claims.

The Commission continues to develop the sharing criteria for FS through examination of the signal to interference ratio (S/I).[84] However, it is unclear why this new metric (S/I) has been suggested since the entire discussion on "interference temperature" has focused on the noise and interference (N+I) levels. Thus, it appears that this analysis has nothing to do with development of an "interference temperature" metric.

In the numerical example provided, the Commission has assumed that the unlicensed device is outside of the main beam of the receive antenna of the licensed service. However, there will certainly be cases where this is untrue and the unlicensed device will be capable of having a

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82 *See NOI/NPRM* at ¶¶ 30, 35, 40, 44-46.

83 *NOI/NPRM* at ¶40.

84 *NOI/NPRM* at ¶¶ 34, 42.

much greater effect on the licensed service. Also, from the discussion it seems that the analysis is based on only one unlicensed transmitter and should be expanded to include an assumed density of unlicensed devices. Another problem with the approach described is that the allowable transmit level for the unlicensed device is based on the received signal level of the licensed transmitter as measured in the unlicensed receiver. In this case, however, there is no way for the unlicensed receiver to know the origin of the power (or rather the PSD) that it is measuring. If the rules for behavior of unlicensed devices were based on the received power it would be possible that an unlicensed device would measure power in a certain band, calculate its allowed transmit level and begin transmitting. Another unlicensed device might then receive power from the licensed transmitter as well as power from a nearby unlicensed transmitter and would then calculate an even higher allowable transmit power and begin transmitting. In this case, each additional unlicensed device would transmit at ever increasing power levels.

As an enhancement to the approach described above, the Commission has proposed the use of DFS to better control the behavior of unlicensed devices. In this case, the device would measure a particular band of spectrum to determine if it was in use at the current time. Based on this measurement, the device would then begin transmitting if the spectrum band was determined to be unoccupied or if the channel was found to be occupied then the device would move to a different frequency, or channel, and begin the measurement process again. This approach has been proposed and adopted in the Part 15 rules for the UNII portion of the 5 GHz band to facilitate sharing between unlicensed devices and some Federal Government radar systems. Since the radar transmitter and receiver are assumed to be in the same physical location (*i.e.,* a monostatic radar system) the unlicensed device is able to discern some knowledge of the signal level and path loss from the radar transmitter. In this scenario, the propagation characteristics (such as antenna pattern effects, polarization mismatch, path loss, *etc.*) from the radar to the unlicensed device can be assumed to be nearly identical to the characteristics in the reverse direction from the unlicensed transmitter back to the radar receiver (assuming that the unlicensed device has not moved a significant distance). Thus, in this one and only case (*i.e.,* monostatic radar systems), there is some level of certainty that the power measured in the unlicensed device is relevant to what effect the transmissions from the unlicensed device may have on the radar receiver. However, in many other scenarios (bi-static radar, point-to-point links, systems using frequency division duplexing, *etc.*) this level of certainty does not exist since there is no way for the unlicensed device to know where a licensed receiver may be located. The current application of DFS (*i.e.*, avoiding frequencies or channels that are determined to be in use) is a fundamentally better approach in terms of reducing the probability of harmful interference as compared to the S/I approach described above. Whereas the DFS approach would cause a device to cease transmitting, the approach based on S/I would allow the device to transmit at higher and higher levels in a band that is being used by a licensed service. If the Commission intends to allow greater use of unlicensed devices it must only allow an approach for automated device behavior that is conservative and does not allow any possibility for "rogue" behavior of devices. Furthermore, the Commission must define the scenarios with as much detail as possible to ensure adequate safeguards are maintained, which the Commission will not be able to do prior to an extensive study and analysis of the multiplicity of RF licensed and unlicensed environments.

In terms of adopting certain power levels measured within the unlicensed receiver, the current levels defined in Part 15 for UNII devices (*i.e.*, -62 and –64 dBm) were based on the monostatic radar scenario described above and should not be applied, in general, to other spectrum bands without further detailed analysis of realistic deployment scenarios. Similarly, it is unclear how the Commission intends to reference any measurement by an unlicensed device to an assumed antenna gain of 0 dBi. Clearly, there may be cases where the signal from a licensed transmitter is arriving at the receiving antenna of the unlicensed device at an angle where the antenna gain could be much less than 0 dBi and this would be further reduced due to a mismatch in polarization. Thus, the unlicensed receiver would misinterpret the received level and would assume it to be with a receiving antenna gain of 0 dBi. While this method has worked in the case of sharing with radar systems as described above, much more research and analysis is needed to apply these assumptions to other scenarios.

The Commission continues to discuss unlicensed operation in the 6525-6700 MHz band and the 12.75-13.25 GHz bands in terms of their "interference temperature paradigm." According to the Commission, its analysis of the "interference temperature" limits suggests that unlicensed devices can be allowed to operate at power levels from 24 to 30 dBm with EIRP levels from 30 dBm to 36 dBm. However, as noted in several of the preceding paragraphs, these conclusions are based on various assumptions for only two simplistic scenarios and the analysis presented in the NPRM does not even seem to make use of the various definitions for "interference temperature" as described within the NOI. Here again it is unclear exactly what "interference temperature" actually is, as well as what the Commission intends as the "interference temperature paradigm." The only consistency that can be seen in the NOI and NPRM is that the Commission is intending to permit increased use of licensed spectrum by unlicensed devices that will be allowed to operate at levels which are 47 dB higher than what is currently allowed. As the Commission has noted in the case of operation in the 13 GHz band, the band allocated to mobile service has been excluded from the discussion. Certainly, this exclusion should remain in effect to protect these systems. Similarly, the 6650-6675.2 MHz band should be granted protection since it is allocated to the passive radio astronomy services.

B. No Need for a Test of Interference Temperature in Occupied Spectrum

The Commission claims that it is difficult to test a spectrum management approach based on real-time adaptation of devices in frequency bands without incumbent services. However, this does not seem to be true, as there could easily be tests carried out in the 5 GHz UNII bands or in the newly approved bands where technical rules have been adopted to realize sharing of the spectrum between unlicensed devices and certain Federal Government radar systems. If the unlicensed devices cannot coexist with themselves then why is it expected that they will coexist successfully in licensed bands? This also raises several questions in terms of how will interference to the incumbent users in these bands be detected and analyzed, if at all. Without any experiments or studies, does the Commission intend to allow new, unproven, adaptive devices to be approved for sale and placed in service in what would be essentially an experiment in interference management at the expense of users and services operating in licensed spectrum bands?

CONCLUSION

For the reasons set forth, Cingular and BellSouth submit that the Commission must terminate its rulemaking without action. If the Commission chooses to continue its general inquiry into the possible use of the IXTemp metric, it should issue a further notice of inquiry with a detailed technical explanation for this metric that responds to the technical and scientific flaws pointed out to date and takes into account the noise floor test data that is in the record. Any further notice of inquiry should also set forth a schedule and procedure for Commission development of more extensive noise floor test data in a variety of bands and locations.

Respectfully submitted,

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April 5, 2004

APPENDIX A: ELECTROMAGNETIC WAVES AND ANTENNA TEMPERATURE

In general, a transmitter sends a certain amount of power to an antenna and this power is radiated in various directions and at various strengths depending on the antenna input impedance and radiation pattern of the transmitting antenna. After propagating through the wireless channel a portion of the transmitted power may be collected by a receiving antenna and then delivered to a receiver. The amount of power delivered to the receiver depends on the amount of power incident on the receiving antenna after propagating through the wireless channel and the receiving antenna characteristics including the radiation pattern, polarization, etc. In general, the power captured by a receiving antenna due to an incoming electromagnetic wave can be expressed as

$$P_A = \left|\vec{S}\right| \cdot A_e(\theta,\phi) \qquad \text{Eq. (1)}$$

where S is the power flux density (W/m^2) arriving at the antenna from a certain angular direction and A_e is the effective aperture of the antenna expressed in square meters (m^2) and evaluated at the angles θ and ϕ indicating the incidence angles in spherical coordinates. Note that the power flux density, S, is a vector quantity having both a magnitude and direction with the direction of power flow given by the Poynting vector $\vec{S} = 1/2 \cdot \mathrm{Re}\left\{\vec{E} \times \vec{H}^*\right\}$ where $\vec{E}$ is the electric field, $\vec{H}^*$ is the complex conjugate of the magnetic field, and Re{ } yields only the real part of the complex value. The incoming wave defined by $\vec{S}$ will also exhibit a particular polarization (e.g. linear, circular, elliptical) that will be discussed further below. In typical analysis of radio systems, Eq. (1) is used to determine the power captured by an antenna due to a single transmitter located at a certain angular direction. Where multiple transmitters or interference sources are present it is necessary to account for the power flux density from each of the individual sources that is incident on the receiving antenna as well as the effects of the radiations patterns, polarization, etc.

To fully characterize the amount of electromagnetic power (or rather power flux density) at a certain point in space, it is necessary to account for all of the possible directions of propagation and wave polarization that may be present. For example, this can be expressed in terms of the total electric field at a certain point (x, y, z) as:

$$\begin{aligned}\vec{\mathrm{E}}_{Total}(x,y,z) = {} & \left[E_x^+\hat{x} + E_y^+\hat{y}\right]e^{j(\omega t-\beta z)} + \left[E_x^-\hat{x} + E_y^-\hat{y}\right]e^{j(\omega t+\beta z)} \\ & + \left[E_x^+\hat{x} + E_z^+\hat{z}\right]e^{j(\omega t-\beta y)} + \left[E_x^-\hat{x} + E_z^-\hat{z}\right]e^{j(\omega t+\beta y)} \qquad \text{Eq. (2)} \\ & + \left[E_y^+\hat{y} + E_z^+\hat{z}\right]e^{j(\omega t-\beta x)} + \left[E_y^-\hat{y} + E_z^-\hat{z}\right]e^{j(\omega t+\beta y)}\end{aligned}$$

Thus, the total electric field at a point in space (x, y, z) is composed of waves traveling in the +x, -x, +y, -y, +z and –z directions and for each direction of travel the electric field may have field components with two distinct polarizations. To accurately measure the quantity represented by Eq. (2) it is necessary to use antennas that are oriented correctly to receive power from each direction and with all of the various polarizations. *See generally* Constantine Balanis, ADVANCED ENGINEERING ELECTROMAGNETICS, John Wiley and Sons, 1989.

Referring back to Eq. (1), the effective aperture of an antenna is defined as

$$A_e(\theta,\phi) = \varepsilon_{ap} \frac{\lambda^2}{4\pi} D(\theta,\phi) \qquad \text{Eq. (3)}$$

where $D(\theta,\phi)$ is the directivity of the antenna in a certain direction given by the angles θ and ϕ, ε_{ap} is the aperture efficiency and λ is the wavelength. Thus, the power collected by the antenna from a single source depends on the power flux density arriving at the antenna from a certain direction and the value of the antenna's effective aperture in that direction. The power that is actually delivered to a receiver connected to the antenna can be expressed as

$$P_R = pqP_A \qquad \text{Eq. (4)}$$

where p is the polarization efficiency (or polarization mismatch factor $0 \le p \le 1$) and q is the impedance mismatch factor $0 \le q \le 1$. Thus, the power delivered from a transmitter to a receiver depends on several characteristics of the transmitter and receiver including the radiation pattern of the transmitting antenna, the fading characteristics of the wireless propagation channel between the transmitter and receiver, the radiation pattern of the receiving antenna, the polarization of the transmitting and receiving antennas, and any impedance mismatch in the connection from the receiving antenna to the actual receiver. As mentioned above, to evaluate the total power at the receiver, it is necessary to add the power arriving at the antenna from each source accounting for the effects of the radiation pattern, polarization, etc.

Note also that the directivity of an antenna is a function of the radiation pattern and is given by

$$D(\theta,\phi) = \frac{4\pi}{\Omega_A} \left| F(\theta,\phi) \right|^2 \qquad \text{Eq. (5)}$$

where the beam solid angle of the antenna pattern, Ω_A, is given by

$$\Omega_A = \int_0^{2\pi} \int_0^{\pi} \left| F(\theta,\phi) \right|^2 \cdot \sin\theta \cdot d\theta \cdot d\phi \qquad \text{Eq. (6)}$$

and $F(\theta,\phi)$ is the normalized radiation pattern of the electric field.

In the analysis of communications systems, it is also necessary to define the antenna temperature which is a measure of how the antenna is affected by the thermal noise (also known as black-body radiation) created by its surroundings. The fundamental definition of antenna temperature, *see* Warren Stutzman and Gary Thiele, ANTENNA THEORY AND DESIGN, Artech House, New York, NY, 1999; John Kraus, ANTENNAS, 2d Ed., McGraw-Hill, 1988, is related to the beam solid angle of the antenna and the antenna radiation pattern and is given by

$$T_A = \frac{1}{\Omega_A} \int_0^{2\pi} \int_0^{\pi} T(\theta,\phi) \cdot P(\theta,\phi) \cdot \sin\theta \cdot d\theta \cdot d\phi \qquad \text{Eq. (7)}$$

where $T(\theta,\phi)$ defines the temperature distribution as seen by the receiving antenna and $P(\theta,\phi)$ is the normalized power pattern, i.e. $P(\theta,\phi) = |F(\theta,\phi)|^2$. In the evaluation of Eq. (7), it can be clearly seen that the antenna temperature for a given antenna can change due to the direction it is pointing in relation to the surrounding temperature distribution. Similarly, it is possible that a given temperature distribution can produce different values of antenna temperature depending on the characteristics of the particular receiving antenna radiation pattern. Note also that the antenna temperature in Eq. (7) does not depend on the antenna polarization whereas the power received from a certain transmitter or interference source would exhibit this dependence, as shown in Eq. (4).

APPENDIX B: CRITIQUE OF THE NPRM

Paragraph # 37:

The great disparity between the current unlicensed power levels and the maximum permitted EIRP of +85 dBm for FS services of 126.5 dB does not exist when determining interference objectives for digital microwave coordination. The maximum EIRP of 85 dBm is based on the old analog microwave systems where transmitter power could be up to 20 watts (+43 dBm) and antenna sizes that could go up to 15 feet in diameter on the longer (50 mile) paths.

In the digital world, typical EIRPs range from 60 dBm to 75 dBm based on a typical 0.5 watt to 2 watt transmitter and 6 to 8 foot standard performance dishes.

When computing interference, the interfering path (C to B) must be below the interference objective for the victim microwave link (A to B).

Victim Microwave Link

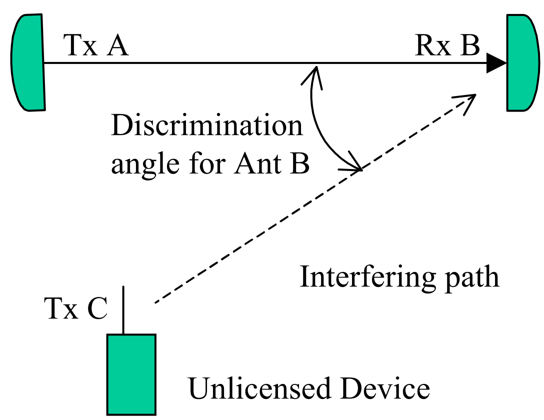

Figure 1

The formula for calculating the operating margin is;

$$EIRP_{(A)} - \text{Path loss}_{(A\text{-}B)} - C/I_{(Coorid)} => EIRP_{(C)} - \text{Path loss}_{(C\text{-}B)} + \text{Disc Loss}_{(B\text{-}C)} \quad (1)$$

A typical microwave link shown in Figure 3 of Exhibit A will be used to calculate the interference margin for an unlicensed device operating 0.1 km from a microwave link with a 20 degree off-axis, discrimination loss, to the microwave path between stations A and B. The Microwave link used in this example has a 3.75 MHz RF bandwidth.

Ref: Exhibit A; Figure 3

Typical microwave transmitter output power;	+ 28.5 dBm
Typical losses on the transmit side;	- 3.0 dB
Typical gain for a 6 foot microwave dish;	+ 38.8 dBi
Typical EIRP=	+ 64.3 dBm

The path loss for a typical 40 km path is 140 dB and the unfaded received signal level is typically –40 dBm.

In addition to the lower EIRP levels, these links are coordinated based on the threshold to interference (T/I) objective and NOT the old C/I objectives used for analog radios.

For analog microwave paths the unfaded signal to interference objective, sometimes called (C/I), is typically 40 dB which is approximately the same as the flat fade margin. However; in the digital world the unfaded C/I is typically 74 dB, see Figure 1 Exhibit A.

Ref: Exhibit A, Equations 1&2
The interference objective (EIA/TIA 10 F) -114.5 dBm
The $C/I_{(Coorid)}$ for a digital link is {-40 dBm- (-114.5 dBm)} = 74.5 dB

For the interfering path (C to B); EIRP = -41.25 dBm/MHz (unlicensed device) with a 20 degree discrimination angle which yields a path loss of 94 dB and a off-axis loss of 43 dB, see Exhibit A, Table 2, 50 meter antenna height. Note that the path loss from the unlicensed device will be greater than the free space loss due to ground clutter. For this reason the modified HATA formula in TIA TR 14.11 is used to calculate the path loss.

Inserting the typical values for the digital microwave path and correcting the EIRP of the unlicensed device for 3.75 MHz bandwidth into equation 1 above yields;

64 dBm-140 dB-74 dB => -35.5 dBm –93 dB - 43 dB which = -150 dBm > -171.5 dBm

Therefore the actual margin for causing interference into a digital microwave system is 21.5 dB not 126 dB as the FCC has implied.

Looking at this from the received signal level, at the receiver input, the receiver can tolerate 21.5 dB of additional interference from ALL interferers before the operating margin is reached.

Referring to Exhibit A Figure 6 the calculated (average of the 3 antenna heights) EIRP from the interfering transmitter for distances of 0.1 Km or less is 30 microwatts or –15 dBm as an aggregate for all interferers as a worst case. Relating this aggregate to the current unlicensed maximum EIRP of –35.5 dBm/3.75 MHz yields a 20.5 dB margin which is within 1 dB of the calculated margin. This would permit a maximum of about 100 users if all users were in the same area of the microwave antenna.

$$\text{Aggregate power} = -35.5\ \text{dBm} + 10 \log 100 = -15.5\ \text{dBm} \qquad (2)$$

When a random distribution of users are considered, the maximum number would be reduced to perhaps 75 or 50 users which is not inconceivable in a "Campus" type of environment.

Under normal FS- FS coordination with other users there are usually less than 3 cases of interference that have to be cleared hence the 5 dB MEA (Ref: Exhibit A). There is also knowledge of where these cases are with respect to the link in question. When considering deploying unlicensed devices in this spectrum there will not be any way to control the number and location of these devices. Furthermore, the microwave receiver will not know how many devices are in use, or for that matter be able to identify and control the unlicensed devices. Therefore the FCC should consider ***reducing*** not increasing the current part 15 limit to insure that there is no harmful interference into the microwave link.

Paragraphs 40 & 41

Dynamic frequency selection (DFS) and/or transmit power control (TPC) methods of interference control require the victim's receiver and transmitter operate in the same frequency band and at the same site, *e.g.,* a radar site and that the propagation path in both directions is the same. Under these conditions, the unlicensed device can make certain assumptions about its transmit power level based on its received signal level. A foreign (victim) microwave receiver will not have a transmitter in the same band and therefore there can be no direct assumptions made about the propagation path behavior. Furthermore, it is unclear whether DFS and TPC will even work when the relative bandwidths are vastly different. The channelized bandwidths in the 6525 to 6700 MHz FS band range from 1.25 MHz to 10 MHz and, depending upon the bandwidths of the unlicensed devices, the methods of control envisioned by the FCC may or may not work.

The coordination procedures and operation of point to point microwave links has been well defined and refined over the years by the NSMA and the operating companies. The coordination process works well because there is a very accurate database of existing users and agreed upon interference objectives against which to design and coordinate a new link. There can be no such database for unlicensed users because of their mobility and uncertainty as to the number of users therefore; the output power of the unlicensed device must be kept below the current -41.25 dBm/MHz to avoid interference. This is shown in the response to Paragraph 37 above.

Microwave sites are no longer the isolated sites that once populated the country in the 1960's and 1970's as part of the common carrier high density long haul telephone trunking network. The microwave links today, and more specifically the links that are part of this NPRM, are deployed in suburban and urban areas where 2 GHz links were once deployed. The upper 6 GHz band is the band of choice for the relocation of 2 GHz links. These links are used to interconnect cellular towers, power utility sub-stations, etc. that are located near populated areas where the distances between the microwave receiver and the unlicensed device can be less than 100 meters.

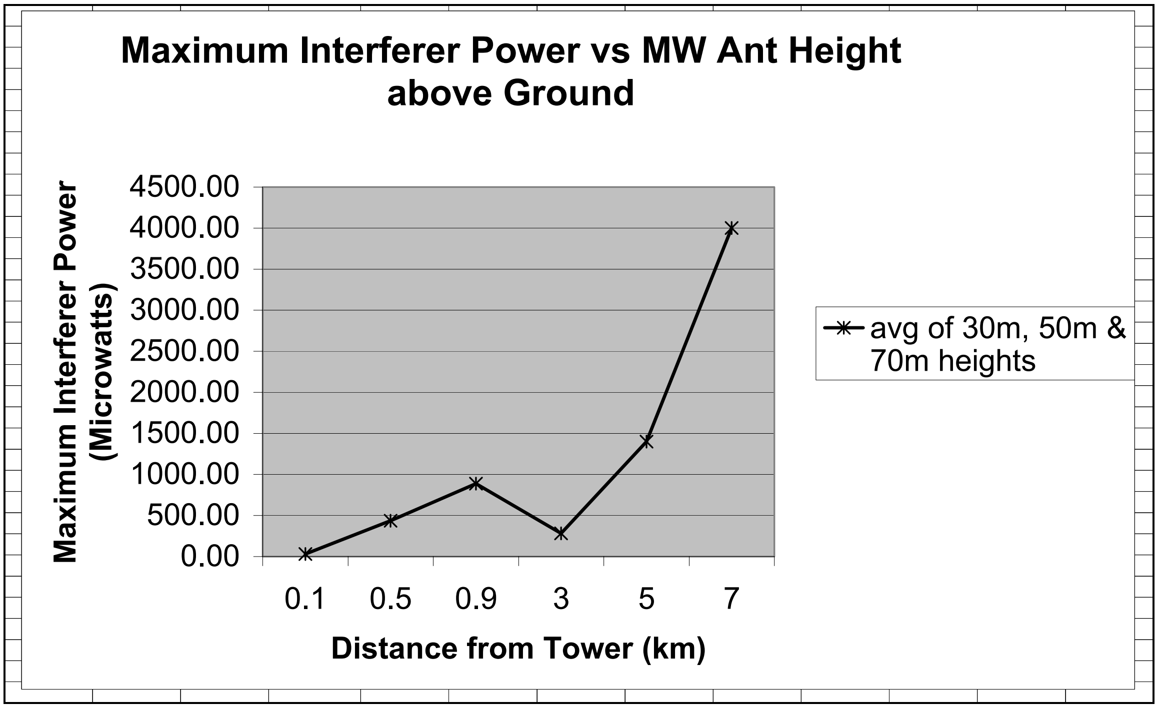

Figure 2

The plot in Figure 2 is calculated using the polar V-V plot for an Andrew PAR6-65 antenna. This curve represents an average of the microwave antenna heights shown in Exhibit A, Figure 6, which were chosen to represent typical mounting heights for suburban and urban cellular towers.

As can be seen in Figure 2 above, and in more detail in Exhibit A, a transmitted signal of 30 microwatts (-15 dBm) at a distance of 100 meters or less can cause harmful interference into an antenna mounted 50 meters above the ground. At a distance of 7 Km, the interfering signal is essentially in the main beam of the microwave antenna, and a transmitted signal of 4 milliwatts (+6 dBm) will cause harmful interference.

For distances of 3 Km and less, the interfering signal is either in a secondary lobe or on the side of the main lobe of the microwave antenna pattern. Therefore, there can be no common or minimum attenuation applied that will not cause harmful interference because of the interaction between distance, antenna height and the related discrimination loss from off-axis arrival of the unwanted signal.

Beyond approximately 6 Km, the unwanted signal is in the main beam of the microwave antenna hence the propagation loss becomes the primary controlling factor. At this point, if there were a co-channel transmitter at the victim receiver site the unlicensed device may have been able to apply a minimum attenuation to avoid interference; however, this is not the case with FS microwave links, as described in our response to paragraphs 40 & 41.

Once these unlicensed devices, which typically have omni-directional antennas, are deployed in the field, there can be no way to control where they will be used consequently there can be no control of the distance. For example, an unlicensed device is used on a rooftop apartment that is

50 feet away from a microwave antenna and 10 degrees off axis. In this case, even the current part 15 level of –41 dBm/MHz is too high by 6 dB.

If somehow an appropriate baseline could be established for the case where microwave antennas are mounted on a tower, it would be no good for the rooftop case since the distances and discrimination angles have radically changed.

Paragraph 42

Typical microwave receivers require a threshold to interference (T/I) ratio of +32 dB for a case of co-channel interference. This ratio requires that the unwanted interfering signal must be below the receivers' static threshold (10^{-6} BER) by 32 dB. As the interfering signal moves away from the center frequency of the desired carrier the (T/I) ratio is reduced and at some point, usually more than one channel spacing, it will become negative. Typical adjacent channel (T/I) ratios are – 5 dB. Additionally the composite fade margin can not be ignored (see Exhibit A). Therefore, the designed composite fade margin must be added to the T/I to achieve an overall unfaded signal to interference ratio (S/I). This ratio is typically 72 dB, but it can range from 62 dB to 80 dB, depending upon the path calculations and modulation, and NOT the 30 to 50 dB presented by the FCC.

The 40 km microwave link illustrated in Exhibit A, Figure 3 is a 12 T-1 system employing 128 QAM modulation with an RF bandwidth of 3.75 MHz. To achieve an availability of 99.999% required the installation of space diversity antennas and a composite fade margin (CFM) of 38.5 dB. This fade margin is based on the receiver's dynamic threshold (10^{-3} BER) of –78.5 dBm. Also note that the receiver's co-channel T/I = 34 dB which is based on the receiver's static threshold (10^{-6} BER) of –75.5 dBm. Therefore, in the example given, the signal to interference (S/I) or carrier to interference (C/I) would be + 69.5 dB.

$$S/I = C/I = CFM + T/I \text{ (co-channel)} - (\text{static threshold} - \text{dynamic threshold}) \quad (3)$$

$$S/I = C/I = 38.5\text{ dB} + 34\text{ dB} - \{-75.5\text{ dBm} - (-78.5\text{ dBm})\} = +69.5\text{ dB}$$

Paragraphs 43, 44 & 45

The microwave band is split into 2 segments: 6525 MHz to 6700 MHz (transmit low) and 6700 MHz to 6875 MHz (transmit high). This separation of the frequency blocks provides the needed isolation between the receive and transmit waveguide branching networks. The stations along a typical microwave rout alternate between transmit low and transmit high frequencies. This NPRM is only addressing lower half of the band, which means that the transmit and receive frequencies of the unlicensed device will both be in the same microwave band segment. Therefore, the signal being received by the unlicensed device will be coming from the distant end of the microwave link, as shown in Figure 3 below.

Microwave antennas are typically mounted 150 feet or more above ground to achieve the required fresnel zone clearance. Under these conditions, the propagation loss is "free space loss."

Unlicensed devices, by contrast, are typically used at ground level where free space loss propagation can not be used. Additionally, since the distant microwave antenna is 40 km away, the propagation losses, as viewed by the unlicensed device, will be in excess of 178 dB (modified HATA model); hence, the transmitted microwave signal may not even be heard by the unlicensed receiver.

If the unlicensed receiver cannot hear the microwave signal, it may try to key on noise bursts (or, worse, on signals from other unlicensed devices), which could result in an overly high transmitted level and a case of interference. As pointed out in our response to paragraph 37, the output power of the unlicensed devices must be kept at or below the current level of –41 dBm/MHz in order to not create a case of interference in a multiple exposure environment.

The 2 GHz microwave clearing methodology employed by PCS operators had to take multiple exposures from both the PCS base stations as well as from the PCS mobile units into account in order to insure that there were no cases of interference into non-cleared microwave links. This same methodology must be employed in the case of allowing the proliferation of unlicensed devices in the 6 GHz microwave band. Since this is not practical in an unlicensed world, the only recourse is to cap the transmit level, as previously stated.

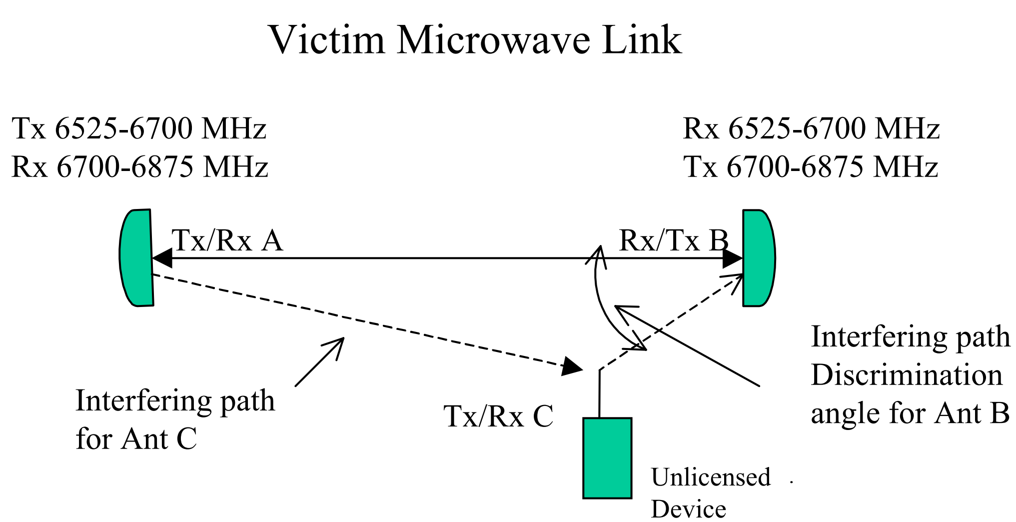

Figure 3

As stated above, the unlicensed device (assumed to be within 100 m of Rx B) may never hear the distant microwave transmitter. At best, receiver C will see the distant transmitter A at a level of -114 dBm {Tx (A) = +64 dBm EIRP -178 dB (A to C loss)}. Therefore, the DFS's detection circuitry may not be able to provide the selection of a clear frequency because of the low received level. The channelized bandwidths in the 6525 to 6700 MHz FS band range from 1.25 MHz to 10 MHz and, depending upon the bandwidths of the unlicensed devices, the DFS circuitry may not work even if it hears the distant microwave signal. Furthermore, the device's TPC may try to transmit at the highest power level because its receiver is seeing a very low signal.

As stated in our response to paragraph 37, the microwave receiver interference threshold is –114 dBm. This translates to a maximum permissible EIRP of –14 dBm for Tx C at a distance of 100 meters from antenna B. Any deployment of unlicensed devices with transmit powers in the +23 dBm range would create a 37 dB case if interference into the microwave receiver. This level exceeds the T/I of 34 dB by 3 dB and lowers the fade margin by 6 dB, both of which will cause unacceptable interference as well as path outages with only slight, log-normal, fading. If there are multiple unlicensed devices in the area of receiver B, all operating at levels of + 23 dBm, it will completely destroy the microwave link's ability to communicate.

It is inconceivable that the Commission can be thinking of deploying unlicensed devices with EIRPs in the range of +30 to +36 dBm within a licensed point-to-point microwave band and not to expect that there will be detrimental interference. As stated in the previous paragraph, these EIRPs are some 40 dB above the calculated –14 dBm aggregate maximum limit for a non-interference case. Furthermore, the physics of propagation and the mechanisms of fading for point–to-point microwave are very different from those experienced with ground-based communications systems. Because of this, there is very little, if any, correlation between the fading that takes place at a 150 feet or more in the air between 2 microwave antennas and the fading that occurs at ground level. Therefore, the microwave could be in a fade while the unlicensed path is not affected, thus causing a severe case of interference and quite probably a service outage for the duration of the fade.

Referring to Figure 3 above, the use of TPC and/or DFS control mechanisms in unlicensed devices would have to rely upon the transmitted frequency and signal levels from the distant microwave site (path A to C). The propagation path between these two antennas is primarily along the ground and is not subject to atmospheric disturbances, while the FS link signal (path A to B) is subject to atmospheric disturbances. Thus the fading on the (A to C) path is independent of, and not correlated with, the fading on the FS microwave path (A to B). This means that the ground path could be relatively undisturbed, while the FS signal path can have a lot of fading activity that the ground based receiver will never see. These two uncorrelated fading conditions will cause harmful interference into the microwave link and the unlicensed device will never know about it and consequently will never be able to correct its power or frequency.

Exhibit A
Interference Temperature

What is interference? Quite simply, it is the presence of an unwanted signal at a victim receiver that causes a disruption of the wanted signal. The extent of disruption has long been a point of many discussions and technical presentations. An acceptable level of interference, by service or band, and a clear technical definition of "interference temperature" are the keys to the FCC implementing this concept. This acceptable level is not the description of harmful interference defined in 47 CFR Part 2.1, as the FCC would like to use in its quest for an interference temperature.

The current definition of harmful interference in the FCC rules can trace its origin to the analog world where there was a single voice channel per carrier and where the level of tolerable interference was primarily subjective. Within the Cellular industry the mean opinion score (MOS) was used to quantify the subjective nature of voice quality based on the level of interference.

In today's digital world the term "harmful interference" has to be redefined in quantitative terms based on the type of service offering being carried over the wireless link. Until this is done, there cannot be any meaningful or workable shift towards an interference temperature approach to managing the radio spectrum.

The microwave links in the FS and FSS service that are part of this NPRM carry a myriad of services, ranging from a single video signal to megabits of data that may be carrying sensitive electric utility control circuits, or many thousands of cellular calls back to a switching office.

The services carried on the FS links in the upper 6 GHz band are a combination of services relocated from the 2 GHz band, as well as new links of varying bandwidths to accommodate many different users and promote more efficient use of the spectrum. These links range from 17 km (minimum allowable) to well over 50 km where long 2GHz paths were replaced.

Digital microwave paths are designed to meet a desired performance measured in error free seconds and in their availability or unavailability, outage measured in seconds per year. The components that make up this performance are its composite fade margin (CFM) and its threshold to interference (T/I) margin. The CFM is defined as the ratio between the receivers' dynamic sensitivity (10^{-3} BER) threshold and the unfaded carrier signal level. The T/I parameter is a measure of the ratio between the receivers' static sensitivity (10^{-6} BER) threshold and the level of total interference. The microwave equipment vendors publish a set of minimum T/I specifications for both co and adjacent channel interference.

The links composite fade margin is primarily the sum of the flat (thermal) and dispersive fade margins. Microwave links with large fade margins will have fewer or no outages due to fading. The predominant mechanism for path outages in the 6 GHz band is multi-path or Rayleigh fading.

The T/I parameter replaced the older carrier to interference (C/I) measurement for digital microwave radios, thereby giving designers a more meaningful specification that is representative of the different modulation coding schemes and modulation bandwidths between like and unlike carriers. It is this threshold, not the composite fade margin, which defines the maximum level of interference for acceptable BER performance of the link. As this ratio decreases, the BER will increase.

TIA TSB 10F defines T/I as the ratio of the wanted to the unwanted signal power that degrades the digital receiver static and dynamic thresholds by 1 dB. Figure 1 shows the typical threshold parameters used to define digital microwave link performance in the presence of fading and interference. The values in Figure 1 are based on a microwave link with a bandwidth of 7.7 MHz whereas, the example used here is based on a microwave link bandwidth of 3.75 MHz. This will shift the values down (lower) by 3 dB.

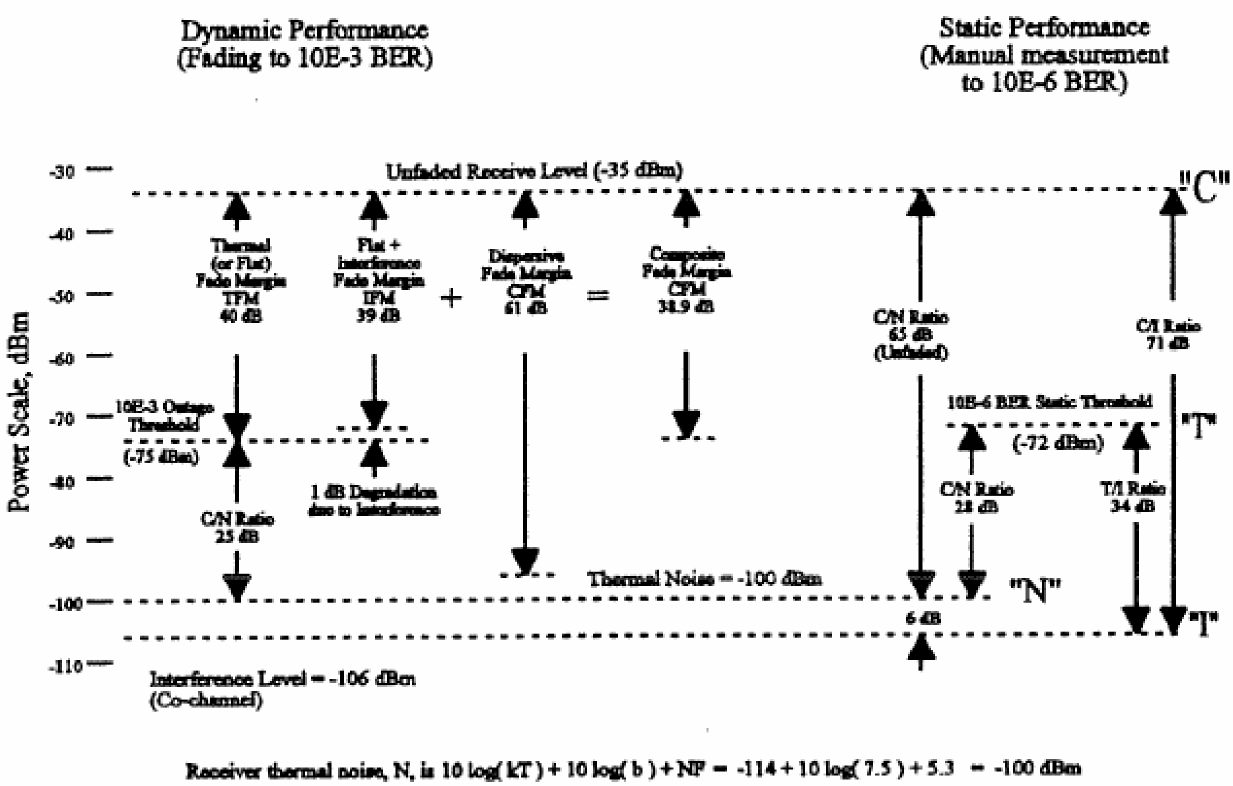

Figure 1

The T/I threshold is used in the frequency coordination process to determine interference margins. At a BER of 10^{-6} the link is considered impaired and it is the point where protective (space diversity) switching should occur. At a BER of 10^{-3} the link will start losing sync (framing) on the digital baseband bit stream and thus it is considered to be failed. Once the microwave receiver goes out of sync it can take up to several seconds for it to regain framing. During that time the baseband is cut off.

Coordination objectives for interference are based on the CO and ADJ channel T/I curves for the model of the victim receiver and the bandwidth and frequency offset of the interfering carrier.

$$I_{(Coordination)} = T_{(Static)} - TI_{(Specific)} - MEA \quad (1)$$

Where: $T_{(Static)}$ = the Static BER Threshold of 10^{-6}

$TI_{(Specific)}$ = the Specific T/I threshold for the victim and interfering bandwidths and frequency offsets.

MEA = Multiple Exposure Allowance

MEA = the greater of either 5 dB or 10 Log ($BW_{(victim)}/BW_{(Interferer)}$)

It is generally agreed, in congested areas, that 5 dB is the default value. This equates to approximately 3 cases of exposures.

The NEC 2600 series microwave radio is typical of the radios used in the upper 6 GHz band. This radio has the following specifications;

Transmitter output power + 28.5 dBm max
Modulation = 128 QAM
Modulation bandwidth = 3.75 MHz
Receiver threshold BER of 10^{-6} = -75.5 dBm
T/I Co-channel = 34 dB
T/I adjacent channel = -5 dB

Receiver outage threshold BER of 10^{-3} = -78.5 dBm (assumed to be 3 dB worse than the static threshold).

The antennas are 6 foot (Category A) similar to the Andrew PAR6-65 dish.

The Interference objective for coordinating this radio system, using equation (1) is:

$$I_{(Coordination)} = -75.5 \text{ dBm} - 34 \text{ dB} - 5 \text{ dB} = -114.5 \text{ dBm} \quad (2)$$

The calculated noise floor for this receiver is:

$$N = -114 \text{ dBm} + 10 \log(3.75) + 5 \text{ dB (typ. noise figure)} = -103 \text{ dBm} \quad (3)$$

Following are 2 examples of microwave path calculations. Figure 2 is a minimum 17 km path, and Figure 3 is a typical 40 km path. Both paths are designed for 99.999% availability.

Figure 2 is a path calculation for a typical upper 6 GHz microwave band link that meets the minimum distance and antenna requirements of the FCC. Note that the thresholds in the sample path calculation are close to the typical thresholds depicted in Figure 1. Here and in Figure 3 most of the outage is due to multipath (Rayleigh) fading. Note that the longer path, Figure 3, requires the addition of Space Diversity to bring the hop back into 99.999% availability. For well-designed microwave paths below 8 GHz, the predominant fading mechanism is Rayleigh fading. The use of the traditional analog flat or thermal margin fade margin can no longer be used to predict outages for digital microwave links. The main source of interference is inter-symbol interference resulting from the varying degrees of differential delay introduced across the baseband. This delay is produced by the frequency selective nature of a Rayleigh fade, and therefore has nothing to do with the unfaded received signal level. Simply increasing the flat fade margin, increasing the transmitter power, will have little or no effect on reducing the system outages due to Rayleigh fading.

A Rayleigh fade is simply the arrival, in the time domain, of a reflected or refracted ray from the main beam at the receiving antenna either ahead of or behind the main signal. This difference in time can be translated into a frequency shift, thus the frequency selective nature. The wider the digital baseband, the more prone it is to multipath disturbances. To overcome some of this effect the manufacturers of high capacity microwave radios equip their receivers with automatic group delay equalizers. These equalizers will correct the arrival times of the incoming signal so that all signals across the baseband will be applied to the demodulator at the same time relative to the transmitted signal.

These equalizers are generally not incorporated in the low to medium capacity radios deployed in the upper 6 GHz microwave band that is the subject of this NPRM. These radios use forward error correction which helps reduce the T/I requirements but does very little to offset the effects of Rayleigh fades.

Rayleigh fading is a frequency selective fade, and it is characterized as having very deep and rapid 10 dB/decade fades, on the order of 20 to 30 dB or more on the longer paths. Multipath fading is the most severe of the atmospheric fades and the one that causes the greatest amount of outage in digital links. The frequency selective nature of a Rayleigh fade causes the group delay across the digital modulation bandwidth to fluctuate and disrupt the decoding process. The receiver's dispersive fade margin is a measure of the receiver's ability to operate in the presence of Rayleigh fading. Rayleigh fading can occur anytime the atmospheric refractive gradient is disturbed.

It is this atmospheric ducting phenomenon that can also cause ducting or steering of the beam away from the receiving antenna hence, the requirement for the addition of a space diversity antenna. This type of fading can occur at anytime of the day but it generally occurs around sunup and (more prominently) around sundown, when there is a change in the temperature and/or the winds.

MICROWAVE RADIO PATH

Path Data Sheet		FCC 03-289						02-Feb-04
	NEC 2600	Equip Config:	H6G MHSBU	Xmit		26.0	dBm	
	16	E1s	Rec Sens:			-78.5	dBm	
Freq.Band:	6.700	GHz	System Gain:			104.5	dB @ BER=10E-3	
Site Name:			(W Site)					(E Site)
	Deg.	Min.	Sec.		Deg.	Min.		Sec.
Latitude:								
Longitude:								
	Azimuth WE:	#N/A	deg.	Azimuth		#N/A	deg.	
Path		17.00	km	//		10.56	miles	
XMT Freq. (GHz) &			6700.000	V		6700.000	V	
						Feeder		
	Free Space		133.63	dB		Use W/G		
	Feeder		3.13	dB		70.00	mtrs Total	
	Miscellaneous		1.00	dB		Equip		
	Absorption		0.15	dB		1	dB Xmtr	
	TOTAL		140.41	dB		1.5	dB Rcvr	
						Ant Size		
	West Antenna		39.80	dB		1.8	M.	
	East Antenna		39.80	dB		1.8	M	
	Transmit		26.00	dBm				
	TOTAL		105.60	dB				
UNFADED RECEIVE SIGNAL			-34.81	dBm				
	FLAT FADE		43.69	dB				
DISPERSIVE FADE			63	dB				
	COMPOSITE FADE		43.64	dB				
CLIMATE-TERRAIN FACTOR					1.00			
		RAIN RATE		K				
	AVERAGE ANNUAL				21	degrees C		
		RELIABILITY						
			ONE WAY					sec/yr
	USER		99.99900%					315.6
FADING SEASON			1.3	mo/yr				37.6
								0.0
			RAIN RATE			#N/A	by Crane	
* PATH RELIABILITY (ONE			99.99988%	* PATH			=	37.6
	w/ SPACE		100.00000%			9.144		0.1
* (2%)	w/ FREQ.		100.00000%	*				0.2
*	w/ HYBRID		100.00000%	*				0.0
* PATH RELIABILITY (TWO			99.99976%	* PATH			=	75.2
	w/ SPACE		100.00000%			9.144		0.1
* (2%)	w/ FREQ.		100.00000%	*				0.4
*	w/ HYBRID		100.00000%	*				0.0

Figure 2

MICROWAVE RADIO PATH CALCULATIONS

Path Data Sheet for:		FCC 03-289				04-Feb-04
Model: NEC 2600		Equip Config H6G HSSD		Xmit Pwr:	28.5	dBm
Capacity:	16	E1s	Rec Sens:	-78.5	dBm	
Freq.Band:	6.700	GHz	System Gain:	107.0	dB @ BER=	10E-3

Site Name:			(W Site)			(E Site)
	Deg.	Min.	Sec.	Deg.	Min.	Sec.
Latitude:						
Longitude:						

Azimuth WE: #N/A deg. Azimuth EW: #N/A deg.

Path Length: 40.00 km // 24.84 miles

XMT Freq. (GHz) & Pol.:	6700.000	V	6700.000	V
			Feeder Type	
Free Space Loss:	141.06	dB	Use W/G	
Feeder Loss:	3.13	dB	70.00	mtrs Total
Miscellaneous Loss:	1.00	dB	Equip Losses:	
Absorption Loss:	0.36	dB	1	dB Xmtr
TOTAL LOSSES:	148.05	dB	1.5	dB Rcvr
			Ant Size	
West Antenna Gain:	39.80	dB	1.8	M.
East Antenna Gain:	39.80	dB	1.8	M
Transmit Power:	28.50	dBm		
TOTAL GAINS:	108.10	dB		

UNFADED RECEIVE SIGNAL LEVEL: -39.95 dBm w/ coupler

* ***************** ************** ***************** **************

FLAT FADE MARGIN:	38.55	dB
DISPERSIVE FADE MARGIN:	63	dB
COMPOSITE FADE MARGIN:	38.53	dB

* ***************** ************** ***************** **************

CLIMATE-TERRAIN FACTOR (c): 1.00
RAIN RATE REGION: K
AVERAGE ANNUAL TEMPERATURE: 21 degrees C

	RELIABILITY		OUTAGE
	ONE WAY		sec/yr
USER OBJECTIVE:	99.99900%		315.6
FADING SEASON MULTIPATH:	1.3	mo/yr	1586.1
RAIN:			0.0
	RAIN RATE (mm/hr):	#N/A	by Crane

*	PATH RELIABILITY (ONE WAY):	99.99497%	* PATH OUTAGE		=	1586.1
*	w/ SPACE DIVERSITY:	99.99993%	* Meters	9.144		21.1
* (2%)	w/ FREQ. DIVERSITY:	99.99981%	*			59.6
*	w/ HYBRID DIVERSITY:	100.00000%	*			0.8
*	PATH RELIABILITY (TWO WAY):	99.98995%	* PATH OUTAGE		=	3172.2
*	w/ SPACE DIVERSITY:	99.99987%	* Meters	9.144		42.1
* (2%)	w/ FREQ. DIVERSITY:	99.99962%	*			119.2
*	w/ HYBRID DIVERSITY:	99.99999%	*			1.6

Figure 3

The mechanisms of a Rayleigh fade can have an effect on one link and not disturb another link in close proximity to it. This means that the victim link can be in a fade, while the interfering link will be immune to the fade and thereby generate a case of interference into the victim link. There is no way of reliably predicting when this occurrence will happen, which is why the industry relies on the threshold to interference (T/I) ratio as the governing parameter for controlling interference into microwave links.

Figure 4 represents the interference path into a victim microwave link. The interfering transmitter (Tx C) is assumed to have an omni directional antenna and the angle to the victim receiver (Rx B) is assumed to be less than 90 degrees.

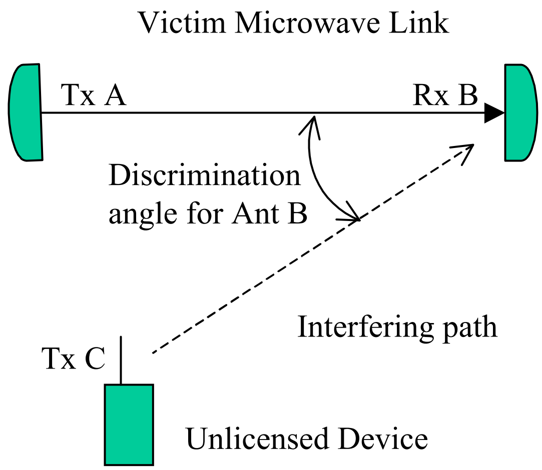

Figure 4

The microwave radio used in this example has an interference threshold of -114.5 dBm, as measured at the receiver. Also, for purposes of this example an Andrew PAR6-65 antenna will be used to calculate the discrimination loss for the interfering signal (Tx C) into antenna B.

The following assumptions have been made in determining the maximum allowable transmitter power for the interfering device.

1. The microwave parabolic dish is assumed to have a conical pattern that conforms to the FCC Category A antenna.
2. The interfering transmitter is assumed to have a unity gain omni directional antenna.
3. All path loss calculations were done with the interfering transmitter at 2 meters above ground level using a modified Hata propagation formula for urban and dense suburban environments.
4. NEC 2600 microwave or similar equipment parameters are used.

The maximum allowed interference into the victim receiver is –114.5 dBm from equation 1 above.

$I_{(Coordination)} = -114.5\ dBm = Tx\ C_{(I)} - PL_{(I)} + G_{(V)} - Disc\ Loss_{(V)} - Line\ Loss_{(V)}$ (4)

Where: $PL_{(I)}$ = Path loss from the Interferer into the victim antenna (C to B)
$G_{(V)}$ = Antenna gain (EIRP) of the victim receiver (B)
$Disc\ Loss_{(V)}$ = Discrimination loss of the Interferer signal into the victim antenna (B)
$Line\ Loss_{(V)}$ = Transmission line loss from the victim antenna to the victim radio rack.

Solving for TxC,

$TxC = - I\ (_{Coordination}) + PL_{(I)} - G_{(V)} + Disc\ Loss_{(V)} + Line\ Loss_{(V)}$ (5)

$TxC = -114.5\ dBm + PL_{(I)} - 38.8\ dBi + Disc\ Loss_{(V)} + 2.06\ dB$ (1/2 feeder + misc. loss from Figure 2)

$TxC = -151.24\ dBm + PL_{(I)} + Disc\ Loss_{(V)}$ (6)

The permitted transmitter power for TxC was plotted for 3 different microwave antenna heights and for distances from the tower of 0.1 to 7 kilometers. The chart and accompanying graph are shown in Table 2 and Figure 6 respectively.

Andrew Model PAR6-65 Standard Performance Microwave Dish Antenna Pattern

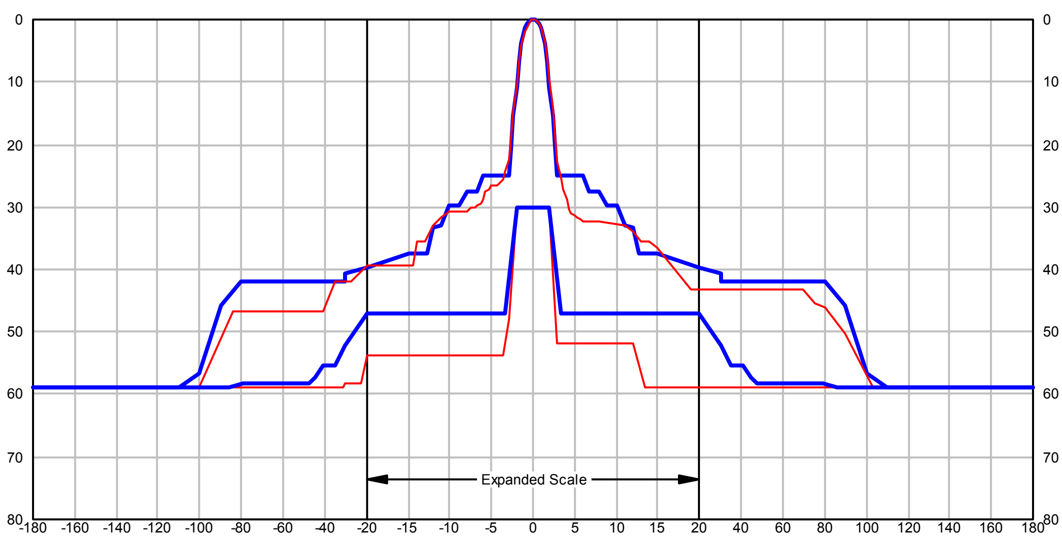

Figure 5

Table 1

Vertical to Vertical Polarization

(Discrimination data is shown for the right hand side of the pattern.
The other half is assumed to be symmetrical as shown in the polar plot above.)

REVNUM:,NSMA WG16.99.050	PATCUT:,AZ	
REVDAT:,19990520	POLARI:,V/V	
ANTMAN:,ANDREW CORPORATION	NUPOIN:,74	
MODNUM:,PAR6-65	0.00,0.00,	12.86,-35.50,
PATNUM:,1290A	0.33,-0.02,	14.00,-35.50,
FEDORN:,RIGHT	0.75,-0.75,	15.00,-36.50,
DESCR1:,	1.00,-1.24,	18.98,-43.14,
DESCR2:,	1.34,-3.37,	70.00,-43.14,
DESCR3:,	1.67,-6.22,	75.00,-45.36,
DESCR4:,	2.00,-9.30,	80.00,-45.96,
DESCR5:,	2.34,-14.07,	90.00,-50.30,
DTDATA:,19971202	2.67,-18.75,	
LOWFRQ:,6425	3.00,-22.69,	
HGHFRQ:,7125	3.34,-25.39,	
GUNITS:,DBI/DBR	3.67,-27.11,	
LWGAIN:,38.7	4.01,-28.78,	
MDGAIN:,38.8	4.34,-30.45,	
HGGAIN:,39.0	4.67,-31.04,	
AZWIDT:,1.80	5.01,-31.38,	
ELWIDT:,1.80	5.34,-31.72,	
ATVSWR:,1.06	5.68,-31.97,	
FRTOBA:,59.0	6.01,-32.22,	
ELTILT:,0	6.02,-32.24,	
PATTYP:,ENVELOPE	8.00,-32.24,	
NOFREQ:,NA	11.00,-32.97,	
PATFRE:,NA	12.00,-33.98,	
NUMCUT:,4		

Table 2

Results of the calculation of maximum permissible TxC output power

MW Twr Ht	Dist of I	PL I	Disc Angle	Disc Loss	Gv	LL	I(Coorid)	Tx C	TxC
Meters	km	dB	deg	dB	dBi	dB	dBm	dBm	Microwatts
30	0.1	95	16.7	40	38.8	2.06	-114.5	-16.24	23.77
30	0.5	120	3.4	25	38.8	2.06	-114.5	-6.24	237.68
30	0.9	129	1.9	6	38.8	2.06	-114.5	-16.24	23.77
30	3	147	0.6	0.5	38.8	2.06	-114.5	-3.74	422.67
30	5	155	0.3	0	38.8	2.06	-114.5	3.76	2376.84
30	7	160	0.2	0	38.8	2.06	-114.5	8.76	7516.23
50	0.1	94	26.6	43	38.8	2.06	-114.5	-14.24	37.67
50	0.5	117	5.7	32	38.8	2.06	-114.5	-2.24	597.04
50	0.9	126	3.2	24	38.8	2.06	-114.5	-1.24	751.62
50	3	144	1.0	1	38.8	2.06	-114.5	-6.24	237.68
50	5	151	0.6	0.75	38.8	2.06	-114.5	0.51	1124.60
50	7	156	0.4	0	38.8	2.06	-114.5	4.76	2992.26
70	0.1	93	35.0	43	38.8	2.06	-114.5	-15.24	29.92
70	0.5	116	8.0	32	38.8	2.06	-114.5	-3.24	474.24
70	0.9	124	4.4	30	38.8	2.06	-114.5	2.76	1887.99
70	3	141	1.3	3	38.8	2.06	-114.5	-7.24	188.80
70	5	149	0.8	0.7	38.8	2.06	-114.5	-1.54	701.46
70	7	153	0.6	0	38.8	2.06	-114.5	1.76	1499.68

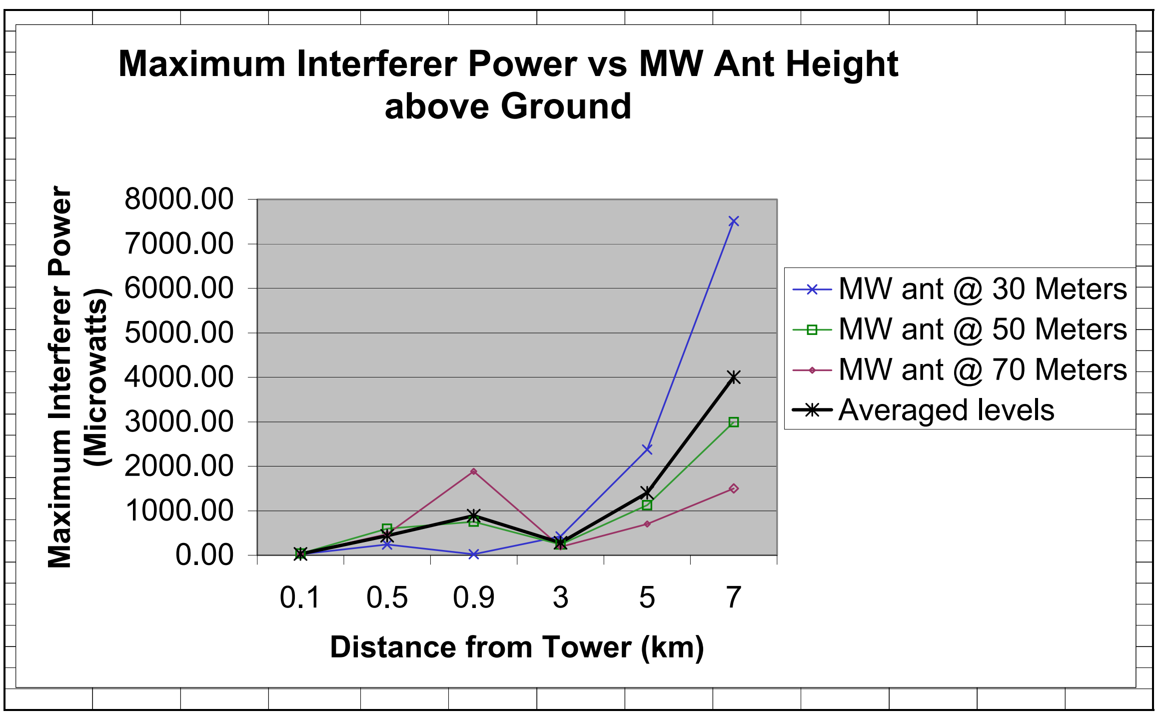

Figure 6