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Federal Communications Commission
Office of Secretary

Before the
**FEDERAL COMMUNICATIONS COMMISSION**
Washington, D. C. 20554

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| In the Matter of | ) | |
| | ) | |
| Amendment of Parts 2 and 15 of the Commission's Rules Regarding Spread Spectrum Transmitters | ) | ET Docket No. 96-8 |
| | ) | RM-8435, RM-8608, RM-8609 |
| | ) | |

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## COMMENTS

1. The Wireless Consumer Communications Section ("the Section") of the Telecommunications Industry Association ("TIA") User Premises Equipment Division hereby offers its comments on the above-captioned matter. The Section's primary interest is the cordless telephone industry, both at 49 MHz and in the Industrial, Scientific, and Medical ("ISM") bands. Many of the Section's member companies offer cordless telephones operating in ISM spectrum under the provisions of §15.247 of the Commission's Rules. The Section's major concern in this proceeding is that any changes made to the Rules not increase the potential for interference to low-power consumer devices such as cordless telephones.

2. Overall, the Section supports the proposals in the Notice of Proposed Rule Making ("NPRM")[1] and offers herein comments on specific issues as requested in the NPRM regarding antenna gain and the minimum number of hopping frequencies and the associated power output limits for frequency hoppers in the 902-928 MHz band.

## THE SECTION SUPPORTS THE COMMISSION'S PROPOSAL REGARDING HIGH-GAIN ANTENNAS

3. The Commission proposes to allow antennas with gain exceeding 6 dBi, without the dB-for-dB power backoff, only in the 5725-5850 MHz band for non-consumer point-to-point systems.[2] The proposed power backoff for such systems in that band is 1 dB for

[1] FCC 96-36, Adopted January 30, 1996; released February 5, 1996.
[2] NPRM at par. 9.

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every 3 dB of antenna gain.[3] The Section understands that this is intended to maintain constant the volume over which the signal from the antenna exceeds a particular level, assuming free-space propagation conditions

4. The Section realizes that a different propagation model would result in a different power backoff formula, and even that it is arguable whether a gain antenna increases or decreases the interference potential of a radiator.[4] Such issues will undoubtedly be raised and analyzed in the Comments of some parties on the NPRM. However, the Section believes that the larger point is that provisions which allow a system to increase its effective isotropic radiated power ("EIRP") above the 6 dBW limit in the current rules will invite new applications, and the attendant potential for increased interference to other devices. This is an example of a more general point made in NPRM, that restrictions on technical parameters not only limit interference directly, but also indirectly by limiting the scope of the applications.[5] The Section believes that allowing high-gain systems in the 915 MHz and 2.4 GHz bands would result in increased interference to cordless telephones and other devices, and therefore supports the Commission's proposal to limit systems with EIRP exceeding 6 dBW to non-consumer, point-to-point systems in the 5725-5850 MHz band.

## IF A REDUCED NUMBER OF HOPPING FREQUENCIES IS ALLOWED IN THE 902-928 MHZ BAND, A QUADRATIC POWER REDUCTION FORMULA SHOULD BE USED

5. In response to a petition from SpectraLink Corporation ("SpectraLink"), the Commission proposes to allow the minimum number of hopping frequencies (currently 50) in the 902-928 MHz band to be reduced to 25 for systems with channel bandwidths of at least 250 kHz, provided the peak power output is no greater than 500 mW.[6] However, comments are requested on potential formulas relating the minimum number of hopping

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[3] NPRM at par. 16.
[4] *See, e.g.*, NPRM at footnote 10.
[5] NPRM at footnote 3.
[6] NPRM at pars. 31 and 33.

channels to the bandwidth[7] as well as the appropriate relationship between the number of hopping channels and the power output.[8]

6. The Section has studied these questions as detailed in the Attachment to these Comments, and concludes that the following limits on the power output would ensure that the potential for interference from a system with a reduced number of hopping frequencies would be no greater than that from a comparable system (with the same emission bandwidth and other characteristics) operating under the existing rules:

> "For frequency hopping systems operating in the 902-928 MHz band: 1 watt for systems employing at least 50 hopping channels. For systems employing less than 50 hopping channels, the lesser of: (1) $(n \cdot \Delta f/26)^2$ watts, and (2) $(m/50)^2$ watts; where $n$ is the total number of system-defined channels from which the actual hopping channels are randomly-selected, $\Delta f$ is the minimum center frequency separation between any two of the system-defined channels, in MHz, and $m$ is the number of hopping channels employed."

7. With this rule, there would be no need to limit the option to reduce the number of hopping frequencies to systems with an emission bandwidth greater than 250 kHz (detailed rationale is given in the Attachment). Nor would there be a need to place a lower limit on the number of hopping frequencies; a "one-hop" (*i.e.*, non-hopping) system operating under this rule would have a power limit of about –4 dBm. Assuming a quarter-wave antenna with 2 dBi gain, the EIRP would be –2 dBm, which is slightly less than the general limit in §15.249. The Section believes that this rule would allow maximum flexibility for designers of frequency hopping systems, while preventing an increase in the potential for interference from frequency hoppers to other devices in the band, such as direct-sequence cordless telephones.

8. Interestingly, the interference analysis in the Attachment suggests that the potential for interference from a frequency hopper is higher for hoppers with wide emission bandwidths

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[7] NPRM at par. 32.
[8] NPRM at par. 33.

than for hoppers with narrow emission bandwidths.[9] Accordingly, the Section does not believe that a power spectral density limit for frequency hopping systems is appropriate. Such a limit would serve in some cases to allow hoppers with wide emission bandwidths to use a higher power output than "narrowband" hoppers, whereas the power output would need to be *reduced* as the hopping channel bandwidth increases, in order to equalize the interference potential of wideband and narrowband hoppers.[10]

9. The Commission denies the petition of Symbol Technologies, Incorporated ("Symbol"),[11] and does not propose to allow an increase in the hopping channel bandwidth in any of the ISM bands. The Section agrees that the maximum hopping channel bandwidth should not be increased in any of the ISM bands. Although interference from increased-bandwidth hoppers could be partially managed with a power-reduction rule such as that proposed herein, increasing the maximum hopping channel bandwidth could introduce new interference scenarios. An example might be a commercial facility requiring both wireless voice communication and wideband wireless data. Currently, wideband data applications can be served using direct sequence modulation, which results in a wideband signal that is stationary in frequency This allows direct-sequence cordless telephones with the capability to select among multiple frequency channels to avoid the portion of the band used by the wireless data system. An increase in the hopping channel bandwidth might encourage the development of wideband frequency hopping wireless data systems, which could result in unavoidable interference between the voice and data systems. Even power limits such as those proposed above may not suffice to manage this interference, since the voice and data applications typically will coexist in close proximity (*e.g.*, in the same office).

10. While it could be argued that it is incumbent upon the customer to select wireless products that can coexist, most customers are not sufficiently knowledgeable about radio

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[9] More specifically, the interference potential depends on the relationship between the emission bandwidth of the frequency hopper and the bandwidth of the receiver passband of the "victim" device with which the hopper might interfere.

[10] The Section is not proposing this, but makes the observation to underscore the point that a power spectral density limit is not justified from an interference perspective

[11] NPRM at pars. 18-25.

interference issues to do so. Moreover, users in office complexes can suffer interference from systems beyond their control. The Section therefore believes that increasing the maximum hopping channel bandwidth will inevitably lead to additional interference problems, and agrees with the Commission that the current emission bandwidth limits for frequency hopping systems should be maintained.

## THE SECTION DOES NOT BELIEVE THAT THE RESULTS OF THIS PROCEEDING SHOULD BE SUBJECT TO CHANGE BASED ON RECONSIDERATION IN THE LMS PROCEEDING

11. The NPRM notes that changes to the rules for the Location and Monitoring Service ("LMS") may be made based on petitions for reconsideration of the LMS *Report and Order*, stating that "Any changes to the LMS rules in response to those petitions may result in modifications to the changes for the spread spectrum regulations under Part 15 proposed for the 915 MHz ISM band."[12] The Section actively participated in the LMS proceeding and is fully aware of its history and the issues involved. Changes to the Part 15 rules were not within the scope of the LMS proceeding; it concerned only changes to Part 90. Provisions of the new LMS rules relating to Part 15 devices are intended to promote coexistence of LMS and Part 15 devices in the 902-928 MHz band, and relate only to the resolution of interference problems between LMS and Part 15. They do not include changes to the Part 15 rules *per se* such as those proposed in this proceeding.

12. The Section contends that the linkage implied by the NPRM between the LMS and instant proceedings is inappropriate. In principal, it affects the context in which comments on the NPRM in the instant proceeding should be made. However, since the NPRM gives no details on which aspects of the Part 15 rules might be affected by reconsideration in the LMS proceeding, relevant comments cannot be provided. This raises the possibility of changes to the Part 15 rules, subsequent to resolution of the instant proceeding, without the necessary review-and-comment process. The Section believes that the outcome of the instant proceeding should not be conditional, pending the outcome of the LMS

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[12] NPRM at par. 34.

reconsideration. If, upon reconsideration of the LMS rules, the Commission finds that further changes to the Part 15 rules are necessary, a new proceeding should be initiated.

## CONCLUSION

13. Overall, the Section supports the proposals in the NPRM to modify §15.247 of the Commission's Rules, but believes, for reasons discussed in the Attachment to these comments, that if frequency hopping systems in the 902-928 MHz band are allowed to operate with less than 50 hopping frequencies, the power reduction formula should be modified as discussed above and in the Attachment to these Comments. With the formula proposed herein, there would be no need to place a bandwidth constraint on the option to reduce the number of hopping frequencies. However, the Section believes that the Commission should continue to maintain the existing emission bandwidth maxima for frequency hopping systems in all of the ISM bands. Finally, the Section does not believe that any linkage should exist between the LMS reconsideration and the rules in §15.247; any decisions made in the instant proceeding should not be subject to later revision based on the LMS reconsideration.

Respectfully submitted,
TELECOMMUNICATIONS INDUSTRY ASSOCIATION

Jay E. Padgett
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Dated: June 14, 1996

**ATTACHMENT**

# THE EFFECT OF SYSTEM PARAMETERS ON THE INTERFERENCE POTENTIAL OF FREQUENCY HOPPING SYSTEMS IN THE ISM BANDS

*Jay Padgett*
*June 14, 1996*

## *Abstract*

This paper addresses the impact of reducing the minimum number of hopping frequencies for Part 15 devices operating in the Industrial, Scientific, and Medical (ISM) bands under §15.247 of the FCC Rules, from the perspective of interference from the frequency hoppers to other devices. Based on an interference model developed here, it is recommended that the maximum power output for hoppers with a reduced number of hopping frequencies be regulated by the following rule:

"For frequency hopping systems operating in the 902-928 MHz band: 1 watt for systems employing at least 50 hopping channels. For systems employing less than 50 hopping channels, the lesser of: (1) $(n \cdot \Delta f/26)^2$ watts, and (2) $(m/50)^2$ watts; where $n$ is the total number of system-defined channels from which the actual hopping channels are randomly-selected, $\Delta f$ is the minimum center frequency separation between any two of the system-defined channels, in MHz, and $m$ is the number of hopping channels employed."

It is shown that with this rule, the interference potential of hoppers with a reduced number of hopping frequencies would be no greater, and in some cases less, than a hopper with the same emission bandwidth operating under the existing rules. With this rule, there would be no need to limit the option of reducing the number of hopping frequencies to devices with an emission bandwidth exceeding some threshold.

It is ***not*** recommended that the maximum emission bandwidths for frequency hoppers be increased, as this could lead to new wideband frequency hopping applications and new interference scenarios, which are beyond the scope of the analysis presented here.

## INTRODUCTION

In ET Docket 96-8, the FCC has requested comments on the possibility of reducing the required minimum number of hopping frequencies (currently 50) in the hopping sequence, for devices operating in the 902-928 MHz band, and on the appropriate relationships between the number of hopping frequencies, the transmitted power, and the hopping channel emission bandwidth. The key question is how these parameters would affect the potential of frequency hopping (FH) systems to cause interference to other devices operating in the band. The purpose of this paper is to address this question, and to recommend relationships among these parameters for Section 15.247 in the FCC rules.

## STATISTICAL INTERFERENCE MODEL

Consider a "victim" receiver, subject to interference from frequency hoppers which are uniformly distributed over area with an average density of $\rho$ transmitters per unit area. Let $r$ be the radius of a circle centered on the victim receiver, which represents the boundary of the victim receiver's "interference zone"; i.e., any frequency hopper within the circle is near enough to the victim receiver to corrupt the reception of its desired signal. Assume that path loss varies as $r^{\alpha}$, and let $P$ be the RF power transmitted by a frequency hopper. If the victim device and the frequency hopper have respective bandwidths of $W_V$ and $W_{FH}$, then the area of the interference zone is:

$$A = \pi r^2 = \begin{cases} C_V \left( \dfrac{W_V}{W_{FH}} P \right)^{2/\alpha} & \text{for } W_V \le W_{FH} \\ C_V P^{2/\alpha} & \text{for } W_V \ge W_{FH} \end{cases} \tag{1}$$

The constant $C_V$ depends on the strength of the signal received by the victim receiver from its companion transmitter and its required carrier-to-interference ratio.

Of interest is the probability that the victim receiver experiences a "hit" from a frequency hopper. This is the probability that there are one or more frequency hoppers inside the interference zone, transmitting within the passband of the victim receiver. If each hopper randomly selects a set of $m$ frequencies for its hopping sequence from a total alphabet of $n$ frequencies ($m \le n$) uniformly distributed across the ISM band with spacing $W_{FH}$, then the expected (average) number of transmitters in area $A$ within the victim receiver's passband at a given time is:[1]

$$K = \begin{cases} \rho A/n & \text{for} \quad W_V \le W_{FH} \\ \dfrac{W_V}{W_{FH}} \rho A/n & \text{for} \quad W_V \ge W_{FH} \end{cases} \tag{2}$$

The actual number of in-band hoppers in the interference zone can be modeled as a Poisson-distributed random variable with a mean value of $K$, and the probability that there are no hoppers in $A$ within the victim passband is $e^{-K}$. The probability of a "hit" therefore is:

$$P_{hit} = 1 - e^{-K} \quad . \tag{3}$$

For purposes of examining prospective relationships between the various parameters governing frequency hoppers in the FCC rules, $K$ is therefore a good measure of the interference potential. In a statistical sense, FH systems with two different sets of parameters that result in the same value of $K$ have the same potential to interfere with other devices

[1] For simplicity, the possibility of partial-band overlap of the victim receiver's passband and the signal from the hopper is ignored here. The assumption that the hopper's frequency separation is the same as its emission bandwidth will be relaxed later.

## PARAMETER RELATIONSHIPS

Combining (1) and (2) gives:

$$K = \left( \frac{W_V}{W_{FH}} P \right)^{2/\alpha} \frac{\rho C_V}{n} \quad \text{for} \quad W_V \le W_{FH} \tag{4a}$$

$$K = \frac{W_V}{W_{FH}} P^{2/\alpha} \frac{\rho C_V}{n} \quad \text{for} \quad W_V \ge W_{FH} \tag{4b}$$

Holding the interference potential (as measured by $P_{hit}$ and therefore $K$) constant for a given $W_V$, $\rho$, and $C_V$ (4) gives:

$$P = k_1 W_{FH} n^{\alpha/2} \quad \text{for} \quad W_V \le W_{FH} \tag{5a}$$

$$P = k_2 (W_{FH} n)^{\alpha/2} \quad \text{for} \quad W_V \ge W_{FH}, \tag{5b}$$

where $k_1$ and $k_2$ are constants. If the victim receiver is a direct sequence system, $W_V \ge 500\,\text{kHz}$. In the 902-928 MHz band, $W_{FH} \le 500\,\text{kHz}$, so (5b) applies. It should be emphasized that $n$ is the total number of frequencies from which the frequencies in the hopping sequence are chosen, *not* the number of frequencies actually used in the sequence.

The total amount of spectrum that can be used by the FH system is:

$$B_{FH} \equiv n W_{FH} \le B_{ISM}, \tag{6}$$

where $B_{ISM}$ is the total available bandwidth (26 MHz in the 902-928 MHz band). Two things are noteworthy here. First, the FCC rules do not require that the entire band be used; the system designer may elect to avoid portions of the band which are known to be used by certain types of devices. In that case, $B_{FH} < B_{ISM}$. Second, a given hopper will use a hopping sequence of $m$ frequencies, which may be less than the total number of frequencies $n$ (alphabet size) from which it selects frequencies for its sequence. That is, $m$ may be less than $n$, and as a result, a given device may not use the entire bandwidth $B_{FH}$ available to it. However, a group of such hoppers spreads its energy over a bandwidth of $B_{FH}$ rather than $mW_{FH}$, so in a statistical sense, $B_{FH}$ is the appropriate parameter to use for assessing the interference probability. This point will be revisited shortly.

Substituting (6) into (5b) gives

$$P = k_2 B_{FH}^{\alpha/2} \quad \text{for} \quad W_V \ge W_{FH}, \tag{7}$$

which suggests that to regulate the potential for causing interference, the maximum allowed transmitted power should vary as $B_{FH}^{\alpha/2}$. The path loss exponent $\alpha$ is often taken as 4 in the mobile/portable radio environment ($\alpha = 2$ corresponds to free-space propagation). With $\alpha = 4$,

(7) gives $P \propto B_{FH}^2$. Assuming a maximum transmitted power of 1 watt when $B_{FH} = B_{ISM}$, the power limit would be given by:

$$P = \left( \frac{B_{FH}}{B_{ISM}} \right)^2 \text{ watts.} \tag{8}$$

## PRACTICAL CONSIDERATIONS

Although the power limit of (8) would theoretically result in uniform interference potential from a statistical perspective, it has two practical problems.

1. Designers may choose to use a frequency separation greater than the 20-dB emission bandwidth, and $B_{FH}$ would be less than $B_{ISM}$ even if the frequencies in the alphabet were distributed across the entire ISM band.
2. A system could use a single-hop sequence (i.e., no hopping) selected from an alphabet of frequencies distributed over the entire band, thereby using a full watt of power with a non-hopping system. While this would be consistent with maintaining the uniform interference probability in a statistical sense, it could result in continuous interference to some particular victim device in a particular segment of the band.

The first problem can be solved by defining the spread-spectrum bandwidth for the system as:

$$B_{SS} \equiv n \cdot \Delta f_{\min} \tag{9}$$

where $n$ is the number of distinct frequencies (the alphabet size) from which the actual hopping frequencies are randomly selected, and $\Delta f_{\min}$ is the minimum separation between adjacent center frequencies in the alphabet; $\Delta f_{\min}$ must be at least equal to the 20-dB emission bandwidth. The power limit of (8) then becomes:

$$P_1 = \left( \frac{B_{SS}}{B_{ISM}} \right)^2 \text{ watts.} \tag{10}$$

To solve the second problem, a formula relating the maximum power to the number of frequencies actually used in the hopping sequence is also needed.[2] From an interference perspective, the worst case occurs when multiple hoppers confine their hopping sequences to the same $m$ frequencies. In that case, (5) suggests that power should vary as $m^{\alpha/2}$ With $\alpha = 4$, this gives the rule:

$$P_2 = \left( \frac{m}{50} \right)^2 \text{ watts, for } m < 50, \tag{11}$$

where $m$ is the number of different frequencies used in the hopping sequence. With the limit of (11), it seems unnecessary to place a lower limit on the number of hopping frequencies. For

[2] Comments on this point are requested in the NPRM (par. 33).

$m = 1$ (i.e., no hopping), (11) gives a limit of about –4 dBm, which is slightly below the limit in FCC 15.249 for non-spread spectrum devices operating in the ISM bands.[3]

The actual power limit would then be:

$$P_{\max} = \begin{cases} \min\{P_1, P_2\} & \text{for} \quad m < 50 \quad \text{(new additional rule)} \\ 1 \text{ watt} & \text{for} \quad m \geq 50 \quad \text{(existing rule)} \end{cases} . \tag{12}$$

Note that for a hopper with the maximum allowed emission bandwidth (500 kHz), $P_1 = P_2$ for $m = n$.

## INTERFERENCE POTENTIAL WITH PROPOSED POWER LIMITS

It is instructive to consider the effect of the proposed power limit on the interference potential. Assuming the alphabet of the FH system consists of $n$ uniformly spaced frequencies with separation $\Delta f$ ($\geq W_{FH}$), then for victim receivers that are wideband compared to $\Delta f$,

$$K = \frac{W_V}{\Delta f} P^{2/\alpha} \frac{\rho C_V}{n} \quad \text{for} \quad W_V \geq \Delta f \tag{13}$$

With $B_{SS} = n\Delta f$ and $\alpha = 4$, substituting the limit $P_1$ in (10) for $P$ in (13) gives:

$$K = \frac{W_V}{B_{ISM}} \rho C_V \quad \text{for} \quad W_V \geq \Delta f , \tag{14}$$

The limit $P_2$ in (11) may be the limiting factor, if $m/50 < B_{SS}/B_{ISM}$, so (14) is actually an upper bound on $K$, for systems that use less than 50 hopping frequencies. Under the existing rules, with $P = 1$ (watt),

$$K = \frac{W_V}{n\Delta f} \rho C_V \quad \text{for} \quad W_V \geq \Delta f \tag{15}$$

Since $n\Delta f \leq B_{ISM}$, it is clear that for $W_V \geq \Delta f$, the proposed power limits ensure that the interference potential of an FH system is no greater than under the existing rules.

With a narrowband victim receiver, allowance must be made for the fact that $W_{FH} \leq \Delta f$, which leads to two subcases: (1) $W_V < W_{FH} < \Delta f$, and (2) $W_{FH} \leq W_V < \Delta f$. For the first case, substituting $P_1$ from (10) into (4a), and assuming that the alphabet consists of $n$ frequencies with uniform spacing $\Delta f$, gives (for $\alpha = 4$):

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[3] The limit in 15.249 is 50 millivolts/meter measured at 3 meters from the device. With free-space propagation, this equates to an effective isotropic radiated power of about –1.25 dBm, or an actual transmitter power output of about –2.8 dBm, assuming a quarter-wave antenna.

$$K = \sqrt{\frac{W_V}{W_{FH}}} \frac{\Delta f}{B_{ISM}} \rho C_V \quad \text{for} \quad W_V < W_{FH} < \Delta f \quad . \tag{16}$$

In general, $\Delta f = xW_{FH}$, where $x \geq 1$, so (16) becomes:

$$K = x \frac{\sqrt{W_V W_{FH}}}{B_{ISM}} \rho C_V \quad \text{for} \quad W_V < W_{FH} \leq \Delta f \quad . \tag{17}$$

For the second case ($W_{FH} \leq W_V < \Delta f$), $A = C_V P^{2/\alpha}$ and $K = \rho A/n = P^{2/\alpha} C_V \rho/n$ (refer to eqs. 1 and 2). Substituting the limit $P_1$ from (10) for $P$, with $\alpha = 4$, gives:

$$K = x \frac{W_{FH}}{B_{ISM}} \rho C_V \quad \text{for} \quad W_{FH} \leq W_V < \Delta f \tag{18}$$

Again, (17) and (18) are actually upper bounds, because of the possibility that $P_2$ may be the limiting factor. Interestingly, (17) and (18) suggest that the interference potential grows with $x$, which depends on the guard bands between adjacent frequencies. However, this actually is not the case, since a victim receiver operating within a guard band will not be subject to interference from the hopper. Adjusting the probability of a hit for this factor gives:

$$P_{hit} = \frac{1}{x}\left(1 - e^{-K}\right) \tag{19}$$

It can be seen that $P_{hit}$ decreases as $x$ increases as follows. Let $K = x\lambda$, where $\lambda$ is the value of $K$ for $x = 1$, so $P_{hit} = \left(1 - e^{-\lambda x}\right)/x$. For any $x > 0$, $P_{hit}$ is a monotonically increasing function of $\lambda$, and $P_{hit} = 0$ for $\lambda = 0$ Since

$$\frac{dP_{hit}}{d\lambda} = e^{-\lambda x} \tag{20}$$

it is clear that $P_{hit}$ grows more slowly with $\lambda$ as $x$ increases. Hence, for any $\lambda$, $P_{hit}$ decreases as $x$ increases, so increasing the guard bands (with all other parameters constant) reduces the probability of interference, as would be expected. The worst case, therefore, occurs when $x = 1$.

Under the existing rules, with $P = 1$, $K$ for the two subcases (with $\alpha = 4$) is:

$$K = \sqrt{\frac{W_V}{W_{FH}}} \frac{\rho C_V}{n} = x \frac{\sqrt{W_V W_{FH}}}{n\Delta f} \rho C_V \quad \text{for} \quad W_V < W_{FH} \leq \Delta f \tag{21}$$

$$K = \frac{\rho C_V}{n} = x \frac{W_{FH}}{n\Delta f} \rho C_V \quad \text{for} \quad W_{FH} \leq W_V < \Delta f \quad . \tag{22}$$

Since $n\Delta f \le B_{ISM}$, the values of $K$ given by (21) and (22) can be no less than those of (17) and (18), respectively. Therefore, the proposed power limits of (10)-(12) ensure that a hopper using less than 50 frequencies will have an interference potential no greater than a comparable 50-hop system operating under the existing rules. The table below summarizes the above relationships, showing the maximum value of $K$ under the existing and proposed power limits (for less than 50 hops).

| CASE | EXISTING | PROPOSED |
|---|---|---|
| $W_V \le W_{FH}$ | $K_{\max} = x\frac{\sqrt{W_V W_{FH}}}{n\Delta f}\rho C_V$ | $K_{\max} \le x\frac{\sqrt{W_V W_{FH}}}{B_{ISM}}\rho C_V$ |
| $W_{FH} \le W_V \le \Delta f$ | $K_{\max} = x\frac{W_{FH}}{n\Delta f}\rho C_V$ | $K_{\max} \le x\frac{W_{FH}}{B_{ISM}}\rho C_V$ |
| $W_V \ge \Delta f$ | $K_{\max} = \frac{W_V}{n\Delta f}\rho C_V$ | $K_{\max} \le \frac{W_V}{B_{ISM}}\rho C_V$ |

The inequality in the third column is due to the fact that the $P_2$ limit may dominate. Note that for the first two cases (victim receivers that are "narrowband" relative to the hopper's emission bandwidth and frequency separation, respectively), the interference potential of the frequency hopper actually *increases* as its emission bandwidth increases. For the third case ($W_V > \Delta f$), the interference potential depends only on the bandwidth of the victim receiver.

## EMISSION BANDWIDTH CONSIDERATIONS

### *Bandwidth-Related Limit on Minimum Number of Hopping Frequencies*

The NPRM also requests comments on whether there should be a formula relating the minimum number of hopping frequencies to the emission (20 dB) bandwidth.[4] The model developed here suggests that if the power limits of (10)-(12) are used, there is no need for a bandwidth-dependent minimum number of hopping frequencies. The greatest concern would be hoppers with narrow emission bandwidths hopping over a small number of frequencies that are selected from an alphabet limited to a small portion of the ISM band. However, the interference potential of such devices would be effectively regulated by the power limits suggested above. As an example, consider a device with $\Delta f_{\min} = 25\,\text{kHz}$, and $n = m = 25$ frequencies. In that case, the limiting factor is $P_1$, which is about –2.4 dBm (0.58 mW). If the system were to use 50 frequencies and operate under the existing rules, it could use a power output of 1 watt, regardless of the design restrictions on the locations of the hopping frequencies. Clearly, the power limits proposed above would make operation on less than 50 frequencies undesirable for such a system. However, if such a system *were* deployed with less than 50 hopping frequencies, those power limits would tend to prevent it from being an interference threat. If the same system were designed to use 25 frequencies evenly spaced across the band, then $P_2$ would become the limiting factor, and the maximum power output would be 250 milliwatts. Again, the interference potential of the system would be reduced compared to its 50-hop, 1-watt version, and the interference would be spread across the entire band, which would prevent an excessive concentration of interference in any

[4] NPRM at par. 32.

particular portion of the band. If the alphabet consisted of 1040 frequencies distributed across the band, 25 kHz apart, with hop sequences of 25 hops randomly drawn from the alphabet, the power limit would be the same (250 mW), as would the potential interference threat to other devices.

It should be noted that the existing rules do not include any relationships between power output, emission bandwidth, and the number of hopping frequencies, nor do they include any relationship between power output and the total bandwidth used by the system ($B_{SS}$). With the power limit proposed above, systems choosing to operate with less than 50 hopping frequencies would have an interference potential no greater (and in most cases less) than a comparable 50-hop system operating under the existing rules (as demonstrated above). Moreover, there may be benefits in allowing even narrowband hoppers to confine their operation to a smaller portion of the band than would be allowed under the 50-hop minimum, provided they operate at lower power. This benefit is mutual; it applies not only to the hoppers themselves, but to other devices with whom they might otherwise interfere.

### *Wideband Frequency Hoppers*

The NPRM denies the petition of Symbol Technologies, Inc. (Symbol), which requested a reduction of the minimum number of hopping frequencies in the 2.4 GHz ISM band, to allow the emission bandwidth to be increased above 1 MHz.[5] The NPRM does not propose to allow any increase in the maximum emission bandwidth for frequency hoppers (500 kHz in the 915 MHz band and 1 MHz in the 2.4 and 5.8 GHz bands). As noted above, the statistical interference model given here shows that frequency hoppers that are wideband relative to the victim receiver actually pose more of an interference threat than narrowband hoppers. It could be argued that for a hopping system that hops over the entire band, the $P_2$ limit proposed above would more than compensate for the increased interference potential of the wideband hopper, because the number of hopping frequencies would necessarily be reduced to accommodate the wider emission bandwidth (for example, with a 5 MHz bandwidth, a maximum of 16 frequencies could be used in the 2.4 GHz band). Although such an argument may be valid from a purely statistical perspective, it ignores the fact, as noted in the NPRM, that increasing the maximum emission bandwidth for frequency hoppers would invite new wideband frequency hopping applications.[6] Such applications could create interference problems where none currently exist. An example is a business environment in which there is a need for wireless data and wireless voice systems to coexist. Wideband wireless data systems such as local-area networks (LANs) currently use direct sequence (DS) modulation because the maximum data rate is higher than with frequency hopping. The spectrum occupied by a DS wireless LAN is fixed. A DS cordless telephone with the capability to select one of multiple frequency channels can therefore avoid the spectrum occupied by a DS wireless LAN. With a wideband frequency-hopping LAN which hops over the entire band, this would not be the case, and the result would be mutual interference. Even the power limits proposed above may not be adequate to mitigate this interference, because the LAN and the cordless telephone systems will likely operate together indoors, in close proximity.

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[5] NPRM at pars. 18-25.

[6] NPRM at par. 23.

## CONCLUSION AND RECOMMENDATIONS

A power limit has been derived which would ensure that, if a frequency hopping system is allowed to reduce the number of frequencies in its hopping sequence below the existing minimum, its potential for causing interference to other devices in the band would not be increased, compared to the interference potential of the same system operating under the existing rules (50 hops and 1 watt power output). The measure of interference potential used is the probability of the victim device receiving a "hit" from the frequency hopper. With the proposed power limit, there would be no need to restrict the option to use a reduced number of hopping frequencies to devices with an emission bandwidth exceeding 250 kHz.

The proposed power limit can be expressed as:

"For frequency hopping systems operating in the 902-928 MHz band: 1 watt for systems employing at least 50 hopping channels. For systems employing less than 50 hopping channels, the lesser of: (1) $(n \cdot \Delta f/26)^2$ watts, and (2) $(m/50)^2$ watts; where $n$ is the total number of system-defined channels from which the actual hopping channels are randomly-selected, $\Delta f$ is the minimum center frequency separation between any two of the system-defined channels, in MHz, and $m$ is the number of hopping channels employed."

It is ***not*** recommended that that the maximum emission bandwidths for frequency hoppers in the ISM bands be increased. Doing so could lead to new interference scenarios which are beyond the scope of the analysis presented here.