European Community. Today, the approximately 4 MHz wide channel bandwidth system with dual channel bandwidth as described by the HomeRF group is authorized under ETSI rules, without any reduction in power from either a 1 MHz-only FH system or an IEEE 802.11b system (all are constrained to +20 dBm max).

Similarly, the identical system proposed by the FCC for operation in the U.S. with dual bandwidth operation and partially overlapping channels up to 5 MHz wide already is authorized in Japan, without any reduction in power from a 1 MHz-only FH system (both would be constrained to about +24 dBm) and actually with about 3 dB higher power than would be allowed for an 802.11b system.

Thus, while the Commission's proposal is an excellent step forward to harmonizing FH rules globally, it represents a major concession in power reduction for WBFH to existing DS and FH systems compared to that in the European Union and Japan. Obviously anyone already building 802.11b products for the global market must be prepared to deal with WBFH systems at much greater relative transmit powers than the Commission is proposing. Rapid adoption of the Commission's NPRM in this matter will enable manufacturers to build low cost and high speed wireless LAN products based on WBFH that can be used to enable broadband in homes around the world.[66] It would be tragic indeed if American consumers were denied this capability.

## CONCLUSION

It is time to update the Commission's spread spectrum regulations to reflect the state-of-the-art. Regulations must evolve to match technological and market evolutions, notwithstanding the somewhat extraordinary view of a few commenting parties that stability and certainty are more important than up-dating regulation, and that the Commission should refuse to "rock the boat" for fear of introducing uncertainty in the Part 15 marketplace.

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[66] See, e.g., Comments of Texas Instruments at 2.

As the bulk of the comments demonstrate, the Commission's proposal to authorize wideband frequency hopping spread spectrum devices is a crucial element of its overall broadband strategy. The authorization of WBFH devices is a necessary step in ensuring that the bandwidth available *in* the home matches the bandwidth available *to* the home.

Moreover, as shown above, the introduction of WBFH devices will not result in unacceptable levels of interference to other users of the 2.4 GHz band. Claims to the contrary arise from individual parties' self-interest rather than from a reasonable assessment of the relevant technical considerations.

Accordingly, the Commission should move quickly to adopt its WBHF proposal and remove the regulatory restrictions that prevent consumers from using FH technologies to meet their need for broad bandwidth in the home.

Respectfully submitted,

THE COMMITTEE FOR UNLICENSED
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November 19, 1999

## APPENDIX 1:

## SUMMARY OF COMMENTING ENTITIES ON WBFH

During the 75-day comment period in this proceeding, the Commission received letters of support from the following 82 entities:

1. 2Wire
2. Abracon Corporation
3. Alation Systems Inc.
4. AsiaPac Distribution Pte. Ltd.
5. Betheltronix
6. BreezeCOM
7. Business Engineering Corporation
8. CEWindows
9. CSA Automated Pte. Ltd.
10. Cal-Chip Electronics
11. Campbell Union High School District
12. Capax Technologies, Inc.
13. Casio Manufacturing Corporation
14. Cayman Systems
15. Cerner Corporation
16. Com21
17. CommAccess Technologies, Inc.
18. Compaq Computer Corporation
19. Copper Mountain Networks
20. DT Research
21. Data Comm for Business
22. Data General, Handheld Computer Group
23. Diablo Research
24. Disman-Bakner
25. Dogear, L.L.C.
26. Donovan Consulting Group
27. Duel Systems
28. Electric Cable, Inc. dba, Connectek
29. Entre Mobility Concepts
30. Ericsson, Inc.
31. FCI Electronics
32. Filbitron Systems Group, Inc.
33. Fujitsu Personal Systems
34. Global Converging Technologies
35. Global Wireless Data
36. Global Wireless Group, Inc.

37. Great American Ventures, L.L.C.
38. HQ Business Centers
39. HomeRF Working Group
40. Home Wireless Networks, Inc.
41. ICL
42. Imagicast, Inc.
43. Intel Corporation
44. KMJ Communications
45. Kinetic Computer Corporation
46. Luna Communications
47. MJS Network Services
48. McKesson/HBOC, Inc.
49. Medical Manager Health Systems
50. Micrilor
51. Micro Design Services, L.L.C.
52. MobileStar
53. Motorola, Inc.
54. National Data Communications
55. National Semiconductor Corporation
56. Network Solutions Group
57. Northeast Data
58. OK Tedi Mining Limited
59. Odyssey Software
60. Open Computing Platforms
61. PC-TEL, Inc.
62. Panja, Inc.
63. Prime Performance
64. Productivity Enhancement Products
65. The Professional Shopper
66. Proxim, Inc.
67. Radiall
68. RadioLAN
69. Randolph Development L.L.C.
70. STMicroelectronics
71. School PCs
72. Siemens Information and Communication Products, L.L.C.
73. Smith Investments
74. South Pasadena Unified School District
75. TAARCOM, Inc.
76. Texas Instruments Israel, Short Distance Wireless Business Unit
77. University of Oklahoma, College of Engineering
78. University of Florida, Computer and Information Science & Eng.
79. Wireless Communications Association International

80. Wireless Data Corporation
81. Wireless LAN Interoperability Forum
82. Dr. John Zaremba

The Commission also received letters of opposition during the comment period from 35 entities. The Opposition generally can be split into three categories.

The first is a group of 15 IEEE802.11b equipment providers and their industry organizations, as follows:

1. 3Com Corporation
2. Aironet Wireless Communications, Inc.
3. Apple Computer, Inc.
4. Cisco Systems
5. Digital Wireless Corporation
6. IEEE 802.11b Wireless LAN Standards Group
7. Intersil Corporation
8. Lucent Technologies, Inc.
9. Network System Technologies
10. Nokia, Inc.
11. Nortel Networks, Inc.
12. Samsung Electro-Mechanics Co., Ltd.
13. Symbol Technologies
14. Wireless Ethernet Compatibility Alliance (WECA)
15. Wireless LAN Alliance (WLANA)

The second Opposition group consists of 11 Bluetooth-member companies, each of whom filed the same form letter:

16. Alantro Communications
17. Clarion Corporation of America
18. Coginitive
19. Gemini Communications AS
20. General Motors Corp.
21. Polycom, Inc.
22. Repeater Technologies
23. SILICOMP, S.p.A.
24. Silicon Wave
25. Solectek
26. Sonera

The third group of opponents can be classified only as "Other." These entities included five manufacturers or representatives of manufacturers of Industrial, Scientific, and Medical ("ISM") equipment who are concerned that expanded Part 15 use of the 2.4 GHz band could lead to calls for ISM emissions limits; one government agency, which does not oppose the Commission's WBFH proposal but questions the adequacy of the Commission's small business analysis; and one party raising miscellaneous comments, as follows:

27. Amana Appliances (ISM)
28. The Association of Home Appliance Manufacturers (ISM)
29. Fusion Lighting, Inc. (ISM)
30. International Microwave Power Institute (ISM)
31. Office of Advocacy, U.S. Small Business Administration (reg. flex. analysis)
32. SCS Corporation (misc.)
33. Sharp Electronics Corporation (ISM)

Another three companies submitted letters that did not specifically endorse the Commission's initiative to enable WBFH. Upon close examination, however, the proposed WBFH regulations do not appear to conflict with the recommendations of these three companies:

1. Kodak Corporation
2. L. Brett Glass
3. Wi-LAN Inc.

A further two companies from the building-to-building bridge industry also sent in letters of opposition based on concerns that WBFH technology might be used in outdoor applications. These two companies are:

4. Clearwire Technologies, Inc.
5. Glenayre Western Multiplex

# APPENDIX 2:

## ANALYTICAL COMMENTS AND INVESTIGATIONS OF WBFH INTERFERENCE TO LEGACY FH AND DS SYSTEMS

### A. THE PERFORMANCE OF LEGACY FH SYSTEMS IN THE PRESENCE OF FLATTER INTERFERENCE PROFILES, SUCH AS WBFH OR LEGACY DS, IS BETTER THAN PREDICTED BY INTERSIL'S SIMPLIFIED ANALYSIS.

A number of letters to the Commission expressed concerns that WBFH, like existing DS systems, might cause excessive interference to existing FH systems that employ variants of the limiter/discriminator type of FM demodulator receiver. The basis of this concern appears to originate from an analysis by Intersil Corporation.[1] However, this analysis considerably overestimates the effects of WBFH upon legacy FH systems such as Bluetooth, OpenAir, HomeRF or IEEE802.11FH for several reasons, as described herein.

CUBE suggests that, in light of the serious analytical flaws described below, the wisest course of action is to consider the actual detailed measurements of interference between these systems as shown in Appendix 3 and to disregard entirely the oversimplified analyses offered by the opponents to the NPRM.

#### 1. Misapplication Of The Theoretical Basis.

The equations are taken out of context and are not applicable in a many places within documents submitted by Intersil Corporation. For example, an equation was shown that states that the noise spectral density at the output of an FM demodulator is proportional to the square of the frequency offset. In extracting this equation from the

[1] Comments of Intersil, "Effects of WBFH Interference on Bluetooth Receiver Reliability," Jim Zyren and Pierre Gandolfo, Sept 24, 1999.

textbook derivation (and it appears in numerous references), two significant underlying assumptions were ignored:[2]

i) The equation was derived specifically for the case of band-limited white noise; as Stremler states, "...if one assumes a white noise spectral density for the discriminator input, the output noise spectral density will be parabolic."[3]

ii) Resulting "signal to noise" ratios are only valid for the case where the desired signal is much, much larger than the "noise" signal. As stated in the same reference used by Intersil (Ziemer and Tranter), "[the equation for output SNR] is valid only if the discriminator input SNR is sufficiently large to result in operation above threshold."

In other words, the squared magnitude response results from a specific set of assumptions that are not valid in this case; analytical results are difficult to derive in low SNR or SIR (signal to interference ratio) cases because of threshold effects. As Stremler states, "Because this [threshold] effect occurs when the noise and signal levels are comparable, it is more difficult to analyze than the high signal-to-noise case."

The next major problem with the Intersil FM demodulator analysis is that key non-linear effects have been ignored. The relevant issue is not analysis in additive band-limited white noise, but the case of two interfering signals. Consider the case of two sinusoids given in Figure A2-1, which would represent two carriers. If we let one phasor be A (the desired signal) and the other B (the interfering signal), then the resultant phasor can be called C. For sinusoids, the locus of the resultant phasor can be described as a hypocycloid, which is the general class of functions as seen in the "Spirograph" toy. The threshold effect results when the signal levels become

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[2] For one example of the complete derivation, see Stremler, Fred G., *Introduction to Communication Systems*, 2nd Ed., pp. 326-331. A similar but less concise discussion is in the Ziemer and Tranter reference mentioned in the Intersil papers.

comparable. The effect of a limiter is to only allow observation of the resultant phasor only when it passes through the real axis. Classical textbook analysis assumes the limited signal is immediately passed through a bandpass filter, which converts the signal back to a rotating phasor, but with significant distortion due to the non-linear limiting operation. The final operations are a discrimination function, in which frequency is converted to a voltage, followed by a final low-pass filtering operation. Some types of more modern FM demodulators may use other operations with different behavior yet.

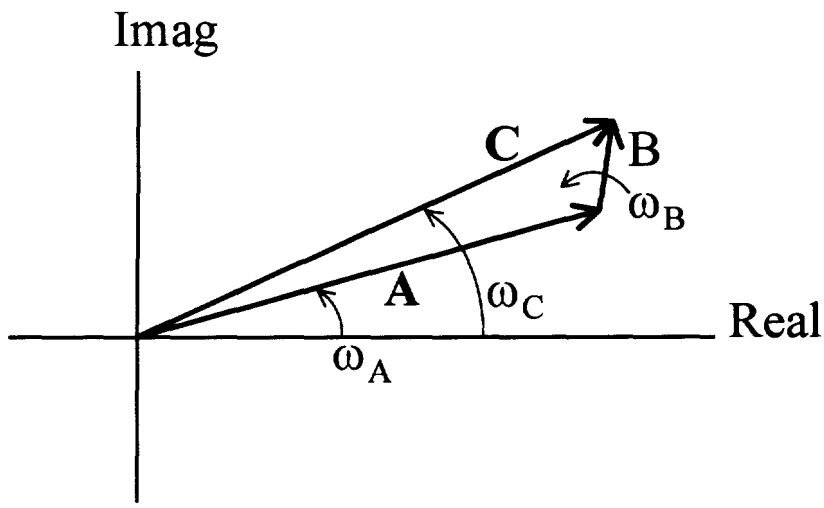


Figure 5-1: Phasor diagram for additive signals before the FM demodulator

So there are in fact two mechanisms at work: 1) A threshold effect that is due to the geometry of the signal phasors; and 2) A limiter that clips the resultant phasor and allows observation of the time this phasor crosses the real axis.

1) The threshold effect has only been analyzed in the literature for the case of

[3] Stremler at p. 328.

white noise, so the derivation is of limited usefulness here. However since the resultant phasor C must be derived from A and B using the law of cosines, the greatest change in C occurs when A and B are of comparable magnitude. In other words, the FM demodulator output becomes highly variable and unpredictable when the signal to interference ("SIR") ratio is close to unity.

2) Furthermore, the limiter tends to suppress all but the largest signal when one signal is significantly larger than all others; thus, for SIR > 10dB or so, the interfering signal causes some jitter in the zero crossing information, but generally is of little consequence. In this regard, there is an error in the Intersil simulation of the limiter as described subsequently here.

Note that it does not matter whether the interference is an FSK signal, a DS signal, or a microwave oven; operation of an FM demodulator with an SIR well above the capture ratio will result in little degradation.

### 2. Practical FM Demodulators Have Varying Characteristics.

The limiter/discriminator described in the Intersil paper(s) is a mathematical construction that is not used in practice; practical demodulators can take on many different forms, and each has advantages and disadvantages. It is simply not accurate to assume a textbook analysis, especially when actual measurements can be made using practical circuits.

There are a number of possible FM demodulators that can be employed in FSK systems including:

i) Slope detector;

ii) Zero-crossing detector;

iii) Phase Locked Loop ("PLL"); and

iv) Quadrature Detection

Each demodulator architecture has its own characteristics, although all typically employ a limiter (with the possible exception of the PLL). For example, a zero crossing counter generates a signal that is proportional to the rate at which the IF signal passes through zero. Zero crossing counters can have perfectly linear frequency to voltage conversion over a broad range of input frequencies and can easily be implemented using inexpensive digital baseband ASIC's. Another example is the PLL, which has a response similar to a classical second order control system - the designer can chose the rise time and overshoot characteristics as necessary or even use multiple feedback loops. PLL's can also be used to get some threshold extension in some cases.

### 3. Actual WBFH Signals Are Concentrated In The Central Portion Of The Channel Bandwidth.

Many WBFH systems likely will use GFSK, which tends to have its energy centrally located, depending on BT and the modulation index, h. The Intersil paper assumes BT=0.5 and h=0.15 in their model. Furthermore, BT and h can be traded against each other to achieve differing design goals, so their particular claimed choice is not representative. For example, lowering BT allows use of a higher modulation index, at the expense of some intersymbol interference ("ISI"). Thus, a WBFH signal could employ GFSK with BT=0.2 and increase the modulation index to approximately h=0.2 while still meeting the -20dBc channel specification. In fact, GFSK with appropriate h

offers BER performance within 1dB of optimum MSK when BT=0.25.[4]

The Intersil paper assumes that the WBFH spectrum is triangular, which is incorrect. In fact, GFSK systems have a parabolic shape in decibels, not triangular. Thus the spectral shape in the Intersil paper is too high toward the edge of the channel bandwidth, which serves to over exaggerate greatly the partially overlapping interference phenomenon.

### 4. Limiting Effects Cannot Be Ignored.

As mentioned above, the non-coherent FSK receiver described in the Intersil comments has a serious error in the model that dramatically affects the results. It shows two received signals of different amplitudes that are limited separately, then phase compared. This is clearly a serious mistake - the two signals are additive in the IF passband as shown in Figure A2-1, so the time of the zero crossing can only be observed for the resultant signal. This dramatically overestimates the impact of interference on the desired signal, and renders the results of the simulation useless.

The correct signal trajectory is shown in Figure A2-2 below. Note that the limiting operation indicates zero crossings, so the interference can only jitter this zero crossing information. No matter what the interference type, as SIR drops below the capture ratio, the ability to recover the modulation will be impaired. Likewise, as SIR increases above the capture ratio, the zero crossing jitter will result in only minor impact on the ability to recover the desired data signal.

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[4] Rappaport, Theodore S., *Wireless Communications*, Prentice-Hall, 1996, p. 264.

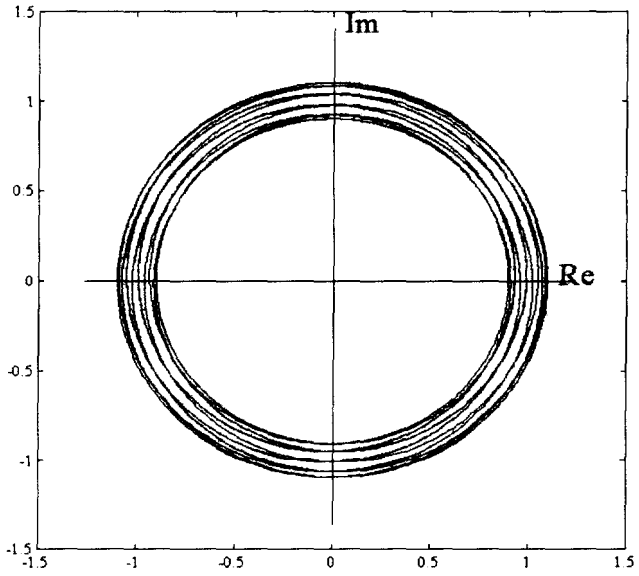


Figure A2-2: Desired and interfering signal resultant locus (SIR=10dB) before limiting

In summary, the analytical models used by the opponents for limiter/discriminator behavior are so inaccurate that any conclusions drawn from the model are completely irrelevant. Since the main purpose of the exercise was to consider WBFH interference on legacy FH systems, the sound engineering approach is to focus on actual measurements for systems that already exist.

Furthermore, modern numerical analysis tools also can be used to simulate these systems accurately. Proxim's simulation of existing FH receivers subjected to WBFH interference shows excellent agreement with the measured results of Appendix 3. However, numerical simulations and measurements do not produce the impressive sets of equations and "sound bite" analytical conclusions that seem to feature so prominently in the Comments of the Opponents to the Commission's NPRM.

## B. WBFH CAN BE SHOWN TO HAVE NEGLIGIBLE INTERFERENCE EFFECTS ON LEGACY DS SYSTEMS COMPARED TO EXISTING FH INTERFERERS.

Opponents of the Commission's WBFH proposal also have made numerous claims that a WBFH signal will cause excessive interference to existing direct sequence systems. In this section, we will show that direct sequence systems which clearly meet the processing gain requirements of 15.247 will be able to withstand a WBFH signal even when the WBFH signal is received at approximately the same power level. The results show that WBFH and existing FH interfering signals have nearly identical effects on legacy DS and, thus, the opponents' interference claims are unfounded. A numerical simulation is performed by generating a DS signal, adding a WBFH signal to it, then processing the resulting signal through a matched filter receiver to recover the original bit sequence in the DS signal. A block diagram of the overall process is given in Figure A2-3.

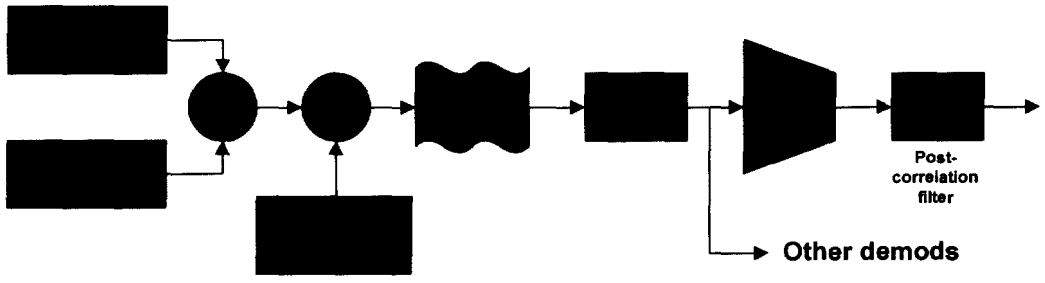


Figure A2-3: Block diagram of DS processing chain with WBFH interferer

Consider an 802.11DS signal,[5] which uses an 11-bit Barker code as its spreading sequence as shown in Figure A2-3 and then add a GFSK WBFH signal to it and adjust

[5] The 802.11DS signal was chosen because it clearly meets the 10dB processing gain requirements of 15.247 both mathematically and experimentally, using either a CW tone or Gaussian noise jamming margin test.

the amplitudes to achieve a desired Signal to Interference ("SIR") ratio. A particularly severe case is when the received signal power for the 802.11DS is the same as the WBFH interference (SIR=0dB). In this case, the signal appearing in the DS receiver passband will reflect both signals, as shown in Figure A2-4; note that we have assumed that noise in the passband is negligible for simplicity, since we are only interested in interference effects here.

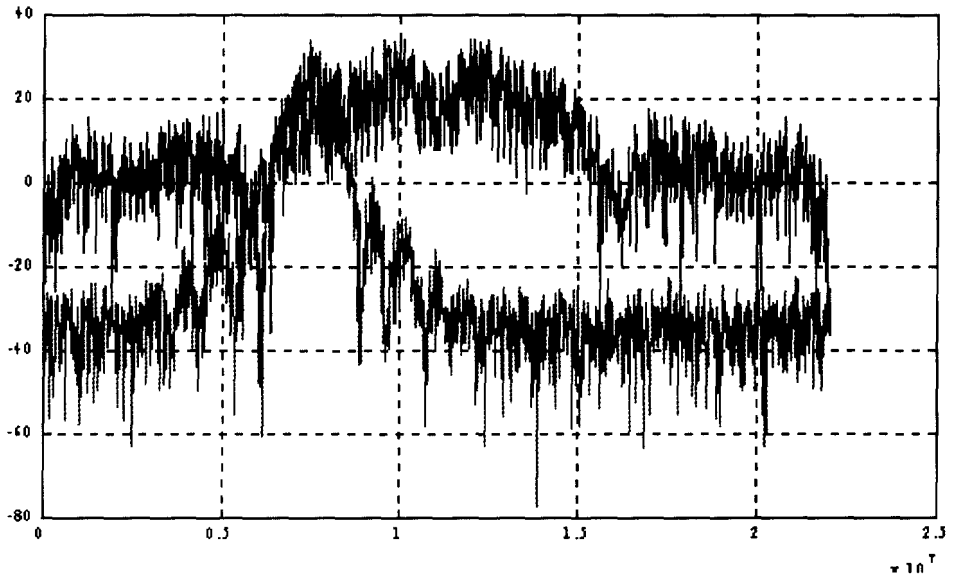


Figure A2-4: 802.11DS (22MHz) and WBFH (5MHz) signal spectra

As the combined signal goes through the correlator, an interesting phenomenon occurs - the 802.11 signal will of course be collapsed by the matched filter properties of the correlator. But since the WBFH signal is uncorrelated with the 802.11 signal, it will appear at the correlator output as the "convolution" (in the power spectrum sense) of the spreading sequence with the WBFH signal as shown in Figure A2-5 below.

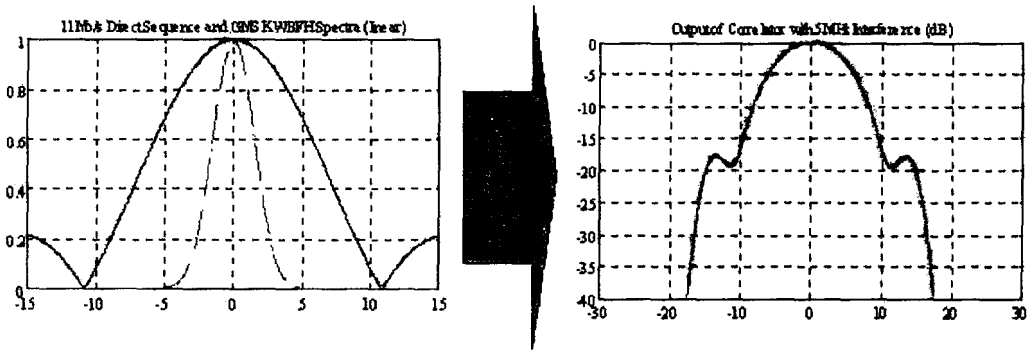

Figure A2-5: Output of DS correlator showing WBFH signal spread over 32MHz

Figure A2-5 shows the 5MHz WBFH signal will be spread out to a signal that is approximately 32MHz wide before entering the post-correlation filter (5+22+5). If we assume the filter is 2MHz wide, then the WBFH signal is attenuated by a factor of 16 (12dB) at the filter output. This is an interesting phenomenon: the DS system actually gets an apparent additional processing gain because the interference is neither very narrowband nor very broadband. Since the DS system has 10.4dB of processing gain to begin with, we would expect it to perform well in this SIR=0dB case, and indeed it does. Figure A2-6 shows the matched filter output, clearly indicating the error-free recovery of the 1-0 pattern that was applied to the receiver.

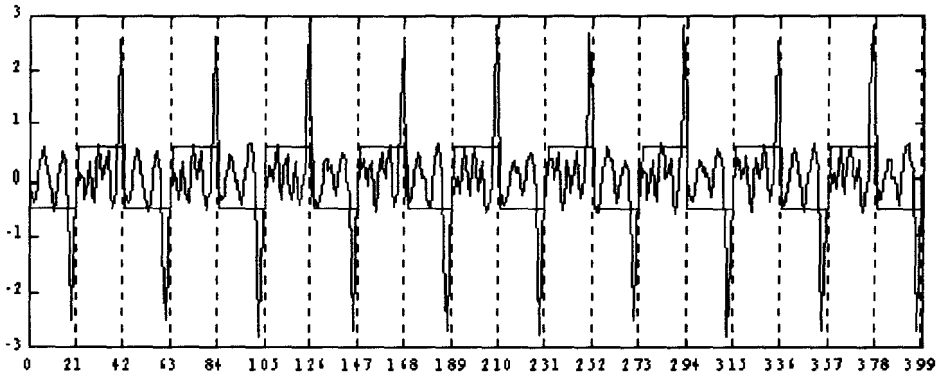

Figure A2-6: Correlator output with original bit stream overlaid

In summary, a DS system that clearly meets the requirements of §15.247 for 10dB of processing gain can perform acceptably well even in the presence of substantial levels of WBFH signals. In fact, the interference power at the post-correlation filter output will be slightly *less* for WBFH than for existing FH signals.[6] Thus, the claimed objection that WBFH will cause undue harm to existing direct sequence systems is completely unfounded.

### C. THE OPPONENTS' OWN ANALYTICAL MODEL SHOWS THAT WBFH HAS A NEGLIGIBLE INTERFERENCE EFFECT UPON LEGACY DS SYSTEMS COMPARED TO EXISTING FH INTERFERERS WHEN VALID ASSUMPTIONS ARE USED.

One of the most extensive Comments put forth by the opponents to the Commission's WBFH proposal was made by an individual, Don Johnson, and submitted under the auspices of the IEEE802.11 Committee.[7] Johnson's Annex contains many pages of apparently complex mathematical derivations mixed with sometimes correct but often erroneous assumptions, which lead to the false conclusion that WBFH systems need substantially greater power reductions in order to achieve interference neutrality compared with existing FH systems.

When more realistic assumptions about baseline comparison references and actual WBFH behavior are made, we see that WBFH has little or even less interference effect on IEEE802.11b high rate DS systems than existing FH systems, *even at equivalent*

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[6] A 1MHz wide uniform power density signal will be spread to 24MHz in the correlator, while a 5MHz signal will be spread to 32MHz. Thus, the interference power at the post-correlator filter will be reduced by 10.8 and 12dB, respectively - so about 1dB less of the WBFH signal makes it through the filter. In reality with FSK signals that are concentrated near the origin as discussed previously, the effect will be less significant.

[7] See IEEE Second Ex-parte letter, document IEEE802.11-99/239.

*transmit powers.*

Consider the following realistic assumptions in connection with Johnson's model of interference from FH systems to DS systems:

1) The DS system is assumed fully connected.
2) 50% of the total FH devices produce sufficient signal strength at any DS device to interfere, consistent with Johnson's area analysis.
3) The DS system comprises M stations operating under the 802.11 CSMA/CA protocol; the contention window doubles upon a failed transmission attempt, and a maximum of 7 retransmissions is employed.
4) The FH system operates without contention; the manner of coordination of FH units is not specified.
5) The utilization of the FH network is an independent variable ranging from 0% to 100%.
6) All packets are same size for the FH and DS systems.
7) No relationship is assumed between the hop dwell and other parameters; none is necessary. The hop dwell will, of course, be longer than the longest frame duration.

Further consider the following parameter values and relationships in the context of Johnson's analysis:

| Parameters | Symbol | Value/Relation |
|---|---|---|
| Packets size | $N_{BYTES}$ | 1500 bytes |
| Total bandwidth | BT | 75 MHz |
| DS data rate | $DR_{DS}$ | 11 Mbps |
| DS bandwidth[8] | $BW_{DS}$ | 17 MHz |
| DS exchange time[9] | $T_{EXCH}$ | 1.51 ms |
| DS packet introduction rate[10] | $\lambda_{DS}$ | DS traffic parameter |
| Slot time | $T_{SLOT}$ | 10 μs |
| Contention window | CW | see below |

[8] Approximately the 20-dB bandwidth; assumed to be the bandwidth which gives the correct probability of FH interfering with DS.

[9] The exchange time for an acknowledged frame in IEEE 802.11 is the sum of the times for: distributed interframe space (DIFS), data frame (PHY header plus data payload), short interframe space (SIFS), and acknowledgement frame (PHY header plus payload).

[10] Per DS Station; when results are presented $\lambda_{DS}$ is converted to Mbps.

| | | |
|---|---|---|
| Mean back-off time | $\overline{T}_{BO}$ | see below |
| Mean DS stations contending | $\bar{k}$ | during CSMA attempt |
| Mean DS stations queuing frames | $M-\bar{k}$ | queued during $\overline{T}_{BO}+\overline{T_{exch}}$ |
| DS frame throughput | S | see below |
| DS frame probability of success | $P_S$ | see below |
| FH factor | $BW_{FH}$ | 1,3,5 |
| FH data rate | $DR_{FH}$ | $2BW_{FH}$ |
| FH packet duration | $T_{PKT}$ | $8N_{BYTES}/DR_{FH}$ |
| FH packet introduction rate[11] | $\lambda_{FH}$ | $0\text{-}1/T_{PKT}$ |
| Probability of bandwidth overlap[12] | $P_{B\ overlap}$ | $(BW_{DS}+BW_{FH}-1)/B_T$ |
| Probability of temporal overlap | $P_{T\ overlap}$ | $1-\exp(-\lambda_{FH}(T_{PKT}+T_{EXCH}))$ |

Of the M stations, k contend for the channel, while M-k queue frames during the subsequent interval, which is the sum of the exchange and the backoff times. Thus, in equilibrium, the probability of frame success must equal the probability that a new frame is offered in the interval between contention events: $\left(M-\bar{k}\right)\lambda_{DS}\left(\overline{T}_{BO}+T_{exch}\right)=P_S$

The throughput, in frames/s, is the mean number of frames offered: $S=\left(M-\bar{k}\right)\lambda_{DS}$

The probability that k contending stations do not suffer collision is the probability that one selects slot n for transmission and all others select a later slot in the contention window: $P_{No_Collision}=\sum_{n=0}^{CW-1}\frac{k(CW-n)^{k-1}}{(CW+1)^k}$

The mean back-off time is the slot time times the mean slot number:

$$\overline{T}_{BO}=T_{slot}\sum_{n=1}^{CW-1}n\frac{k(CW-n)^{k-1}}{(CW+1)^k}=T_{slot}\bar{n}$$

The mean contention window is the average over the retransmission/back-off process:

[11] For entire FH system; when results are presented $\lambda_{FH}$ is converted to Mbps.

[12] These are the probabilities that the DS frame experiences overlap in frequency/time with a frame from the FH system; from Johnson's formulation, but without assumptions about the values.

$$\overline{CW} = \frac{\sum_{n=3}^{2+N_{tries}} CW_n \left(1-\frac{P_S}{k}\right)^{n-3}}{\sum_{n=3}^{2+N_{tries}} \left(1-\frac{P_S}{k}\right)^{n-3}}$$

The probability of frame success is the probability that no collision occurs multiplied by the probability that no interfering FH frame overlap occurs:

$$P_S = P_{No_Collision}\ (1-.5\,P_{B\,overlap}\ P_{T\,overlap})$$

The above equations can be solved self-consistently by numerical iteration. Figures A2-7 and A2-8 show surface plots of DS Throughput vs. DS Offered Traffic for interfering FH traffic ranging from 0 to 100% of FH capacity. When the FH system carries no traffic the curve represents standard CSMA/CA behavior. The presence of some level of FH traffic causes a decrease in DS system throughput, but only after the DS system has begun to interfere with itself. This result makes sense: the DS system responds to lost frames by "backing off," whether lost to interference or contention.

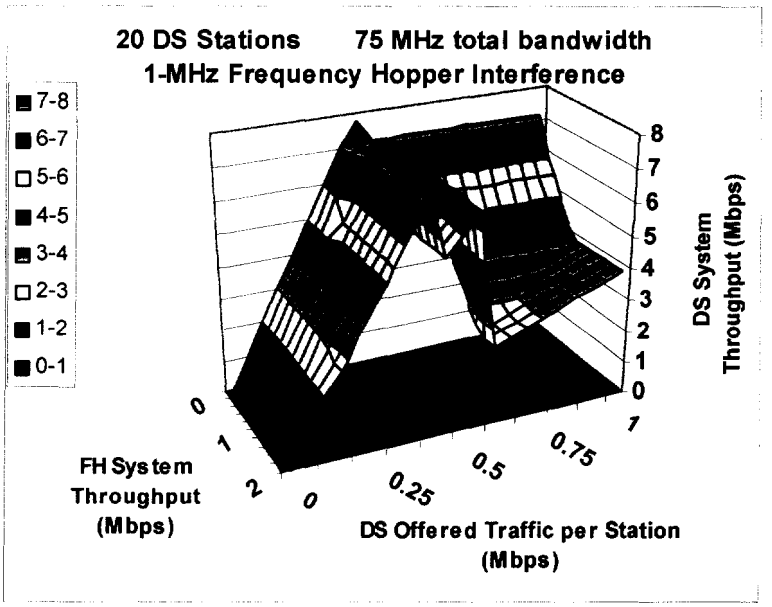


Figure A2-7: IEEE802.11b Throughput versus traffic with Existing FH

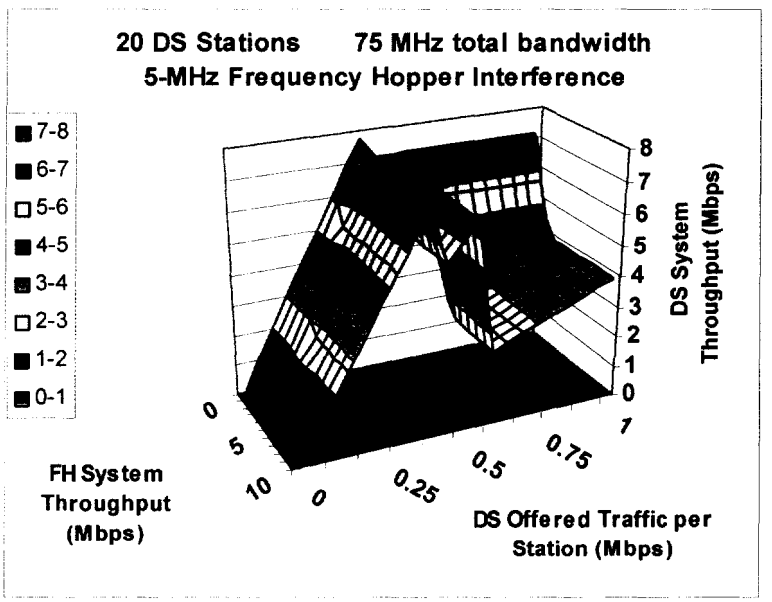


Figure A2-8: IEEE802.11b Throughput versus traffic with WBFH

It is interesting to note the similarity in these curves for DS Throughput vs. Offered Traffic when the FH systems are at maximum capacity. While this is

reasonable, it must be remembered that the two FH systems are then delivering substantially different capacity: 2 Mbps for the legacy FH, and 10 Mbps for the WBFH.

Another view of this situation can be had by examining the DS Throughput vs. Offered Traffic curve when the existing FH and WBFH systems are operating at 2 Mbps, which is shown in Figure A2-9. WBFH in a high DS traffic situation actually causes *less* interference because it is on air less often than existing FH systems for a given FH traffic rate.

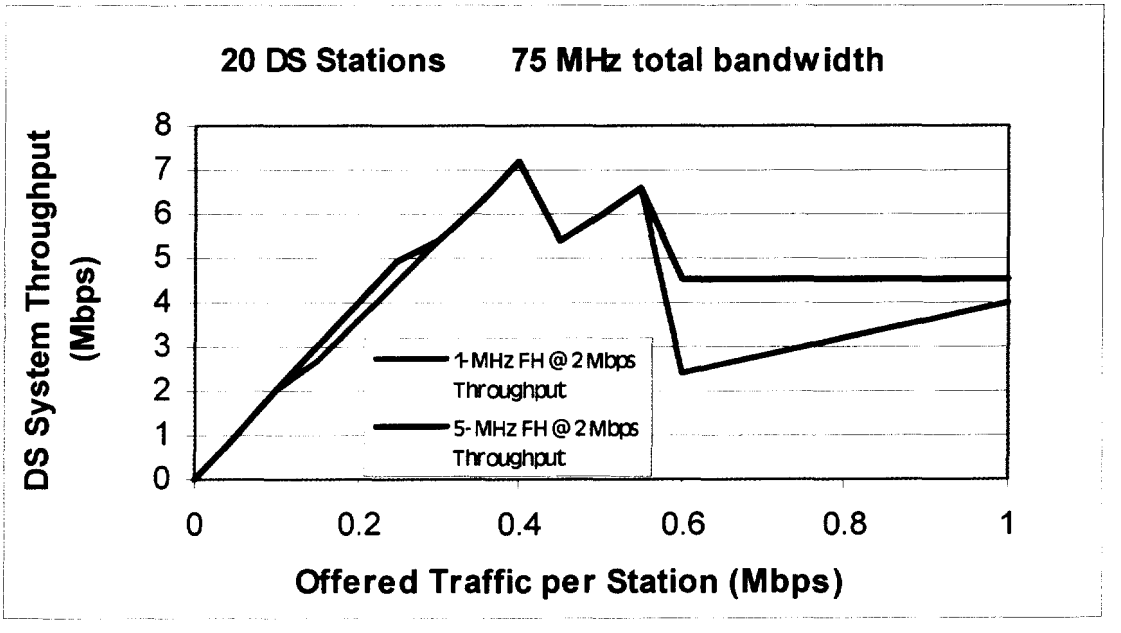


Figure A2-9: IEEE802.11b Throughput versus traffic for Existing FH and WBFH at identical 2 Mbps traffic levels

In summary, there is no analytical justification for the assertion that WBFH will cause additional interference to existing DS systems compared to the interference already caused by existing FH systems. Reasonable analytical approaches show just the opposite - that what little effect WBFH has on legacy DS systems is actually to *reduce*

interference. These results are in complete agreement with the detailed measurements of Appendix 3. Thus, when the additional and substantial power concessions of WBFH are also considered, it is a complete mystery from a technical viewpoint why DS proponents are not welcoming WBFH as the superior FH solution for high data rates so far as their own interests in minimizing DS interference are concerned.

# APPENDIX 3:

# EXPERIMENTAL INVESTIGATIONS OF WBFH INTERFERENCE TO LEGACY FH AND DS SYSTEMS

## A. MEASUREMENTS OF SIGNAL TO INTERFERENCE RATIOS IN LEGACY FH AND DS RECEIVERS.

This Appendix summarizes detailed measurements of actual FH and DS receivers under carefully controlled conditions to determine the relative interference effects of different interfering signal sources, including existing FH and DS systems and HomeRF's proposed WBFH system.

Opponents of the Commission's WBFH proposal made a great variety of assertions of increased interference in certain arcane scenarios. The results of this experimental investigation clearly supersede the unsubstantiated assertions and convenient analytical hypotheses that certain opponents made in their comments.

From these results, it is apparent that WBFH interference has no significant effect on legacy FH systems compared to interference from existing DS and FH systems. In fact, when the substantial power reductions are considered, the effective interference is much less. As for WBFH interference on a legacy DS system such as the Opponents' own IEEE802.11b - there is no net effect relative to existing FH interferers precisely as predicted from two different analytical techniques in Appendix 2. Again, when the WBFH transmit power reductions are considered, the net effect to legacy DS systems is one of substantially reduced interference.

## 1. Measurements Of Signal To Interference For Legacy FH.

This section addresses interference between the proposed WBFH radios and legacy FH systems operating with a 20 dBc bandwidth of 1 MHz. In a set of four experiments, the immunity of a commercially available 2.4 GHz frequency hopping wireless data link[1] to four types of interference was measured. The interfering sources included an unmodulated CW source, another commercially available 2.4 GHz frequency hopping transmitter,[2] a 2.4GHz direct-sequence transmitter,[3] and an early prototype of a WBFH transmitter complying with the proposed rules set forth in the NPRM.[4]

The devices under test were connected as shown in Figure A3-1, using double-shielded cables. The 0–81 dB variable attenuator allowed 1 dB steps. A 2.4 GHz connection was established between units 0 and 2. Unit 1 was the interference source and was configured to be a CW source, an IEEE 802.11FH, a direct-sequence ("DS"), or a WBFH transmitter. The WBFH modulation parameters (h = 0.27, BT = 0.28) result in a spectrum with a 20dB bandwidth of approximately 3.6 MHz. This is approximately equivalent to the planned WBFH system of HomeRF.

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[1] The target legacy FH system is a Proxim OpenAir compliant 2.4 GHz product that complies with existing 15.247 FH rules. This product was referenced by Intersil as being representative of the legacy FH devices that Intersil asserts will be unduly harmed by WBFH interference.

[2] An IEEE802.11FH compliant device was used as an interference source. This is an appropriate baseline for FH interference since the Opponents use it as a baseline as well.

[3] A commercially available IEEE802.11b radio was not used since the vendor's control software did not allow access to the continuous transmit mode. A direct sequence transmitter prototype with a 20dB bandwidth of 17MHz, with a similar transmit spectrum as allowed by the IEEE802.11b protocol was used, as described later in the text.

[4] A photo and brief description of the prototype system is given near the end of Appendix 3.