Digital Networking With the WA4DSY Modem - Adjacent Channel and Co-Channel Frequency Reuse Considerations

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ABSTRACT

The explosion of digital communications in the world and the continued growth of amateur packet radio, networking with high speed modems is becoming a reality. The Dale Heatherington WA4DSY modem [1] has given the Amateur Radio world the means of implementing the high speed networks with a 56 kb/s Minimum Shift Keying (MSK) modem. However, little is known about the performance of the modem when it is closely spaced, in frequency and proximity, with wide band and narrow band carriers. This paper investigates the performance of the WA4DSY modem with adjacent and co-channel interference for the purpose of providing tools to network planners, frequency co-ordinators and average users, for use in planning and implementing high speed digital networks.

1. Introduction/Background

1.1. The Digital World

The world of communications is going digital. With high speed ISDN systems replacing analog telephone networks, digital television compression replacing analog FM distribution of television signals on satellites, digital High-Definition-Television and digital cellular telephone systems in North America and Europe soon to be introduced, the real world is digital now. Amateur Radio has started going digital as well, but with the technology becoming available from the new developments, it is inevitable that amateur radio will begin experimenting with more digital technology. Some of the applications which will be vying for spectrum in the new digital amateur service will be:

- digital voice repeaters using digital cellular technology;
- digital FSTV at 1.5 Mbps using digital compression techniques;
- digital SSTV at 56 kb/s (or less) using digital video conference and digital compression techniques;
- high speed packet networks; and,
- digital voice and data trunking for inter-city links

With' all of the possible applications for digital communications in the amateur service, the very limited allocations for wide band data transmissions and digital voice repeater systems in the future, the task of coordinating the networks to avoid mutual interference appears daunting.

1.2. Ottawa Digital Network Expansion Plans

In the Ottawa area a 56 kb/s Metropolitan Area Network (MAN) has been in operation for some time[2] . New users have continued to join the network and two of the area PBBS's are on the MAN. A decision was mad8 that a second digital repeater, using the Doug Heatherington, WA4DSY 56 kb/s modem (hereafter called the DSY modem), would soon be required. The existing repeater is a cross-band full-duplex bit-regenerating repeater that receives on 220 MHz (Canadians still have access to the 220 to 222 MHz band) and transmits on 430 MHz.

This decision, however, included two key questions:

- how close could the two high speed carriers be placed on both the transmit frequency and the receive frequency; and,
- how close could they be to local Narrow Band FM (NBFM) voice and packet carriers.

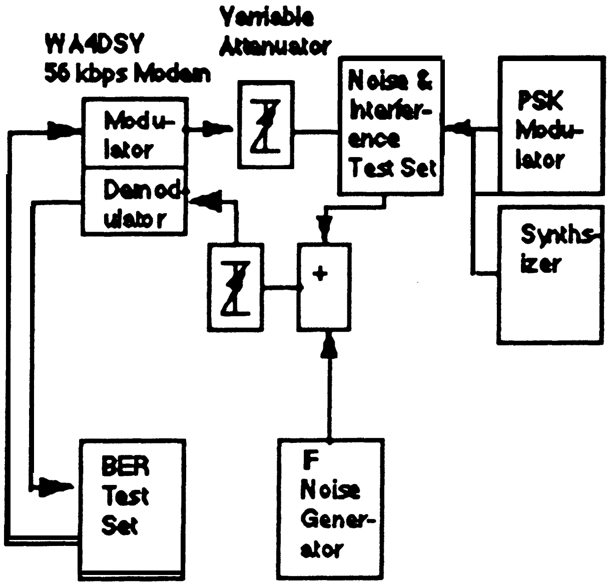
This paper investigates the effects of co-channel and adjacent channel interference due to NBFM and wide band digital carriers for the purpose of determining the minimum channel frequency spacing and network; distance spacing, and provides tools for network planners to US8 in coordinating digital networks.

2. Test Set Up

The test set up used is shown in Figure 1. The author was fortunate to have access to the set-up, which is normally used for testing and characterizing satellite data modems in the presence of interference, at the company where he is employed.

Figure 1

Test Set-Up



Bit-Errof-Rate (BER) was the measure of performance of the modem. The BER was measured using a BER Test Set which sends a sequence of random bits to the modulator and then measures the number of incorrect bits received from the demodulator. The output signal form the modulator was combined with noise generated by the Intermediate Frequency (IF) Noise Generator and was fed back to the demodulator. It was found that the demodulator was fairly sensitive to the power level received so a variable attenuator was placed at the input to the demodulator so that the signal could be attenuated when necessary. By varying the output level of the modulator by using an external Variable Attenuator the Energy-Per-Bit-to-Noise-Density-Ratio (E_b/N_0) could be varied.

For the NBFM tests a synthesizer was used to generated an FM modulated signal with 5 kHz deviation and a 1 kHz tone as the interfering signal. The signal was inserted in the Noise and Interference Test Set where the Carrier-to-Interference-Ratio (C/I) could be set and maintained. The signal from the Noise and Interference Test Set was added to the thermal noise and then to the demodulator.

For the wide band digital interference a commercial Phase-Shift-Keyed (PSK) satellite modem was used as the interfering carrier. A second DSY modem was not available at the time the tests were performed so the PSK modem was substituted. However the PSK modem was of similar bandwidth and similar spectrum shape compared to the DSY modem, for the main lobe.

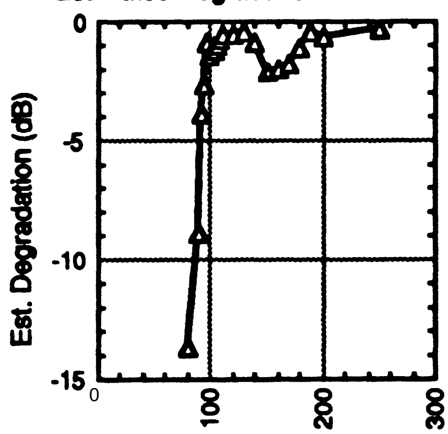
3. Nominal Performance

The tests were performed to determine the degradation due to the presence of the interference. This requires that the nominal performance be characterized. In an ideal world the only degradation on signals is thermal noise which is introduced into the receiving system. It is possible to simulate both the ideal world and the real world by performing tests on an 29 MHz IF loop-back basis. The affects other Radio Frequency (RF) equipment will not be significant on a properly aligned system.

The performance measured was on a modem the author was building up for use on the Ottawa MAN. The actual performance measured may not conform to what other users achieve. The tune up procedures described in the modem Manual were followed, but no attempts to optimize performance

Figure 2

Estimated Degradation Narrow Band FM



were made. However since the important point of the experiment is to determine typical relative performances, the absolute measurements are not as significant, since all conclusions will be based on relative performance.

Figure 2 shows the BER versus E_b/N_o performance of the DSY modem used in these tests and is considered the baseline performance.

For the tests that follow the BER is measured and is compared to Figure 2 where an "equivalent E_b/N_o", $(E_b/N_o)_{eq}$, is determined. The $(E_b/N_o)_{eq}$ is called equivalent because the interference is not noise, but causes a BER equivalent to an E_b/N_o. The $(E_b/N_o)_{eq}$ may be used to determine the degradation in performance in dB and, as well, and equivalent interference noise. The equivalent interference noise could then be used to add to link budget calculations for Veal" systems, and thus eneable the network planner to determine the approximate performance expected based on the level of interference expected.

The BER's measured above includes the on-board modem scrambling. The descrambler, which is a shift register and nor gates, tends to multiply errors. That is if the demodulator makes one bit error the descrambler will output a multiple number of errors. However scrambling is necessary to spread the energy evenly over the bandwidth of the carrier and is recommended for use, so it was used for all tests performed.

4. Performance With Interfering NBFM Carriers

In many band plans wide band digital modes are adjacent to NBFM voice and NBFM packet. These tests will give frequency coordinators and wide band data users tools to use in determining frequency plans for wide band digital systems. It should be noted that no attempt has be made to characterize the interference from the wide band data into NBFM in these tests.

4.1. Adjacent Channel Interference

The C/I was set at -10 dB (the interfering carrier had 10 dB more power than the wanted 56 kb/s carrier at the demodulator input) and a nominal Eb/No of 18.5 dB-Hz and the interfering carrier was stepped from 250 kHz offset. The BER was measured at each frequency and is given in Table 1. From Figure 2 an $(E_b/N_o)_{eq}$ was determined and a degradation from nominal were calculated. The Block Error Rate (BLER) was also measured for 1000 bit blocks, approximately the same number of bits as a typical packet used in Amateur Radio. The BLER would be a reasonable estimate of rate Of lost Of discarded packets.

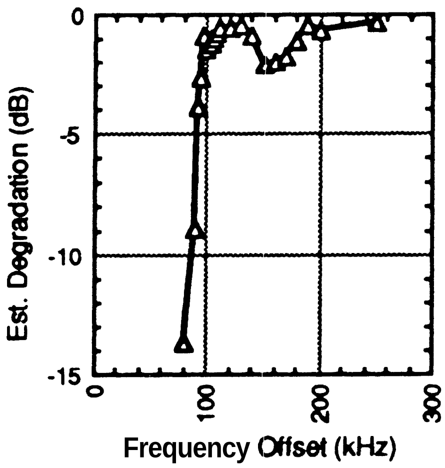
Table 1

NBFM Adjacent Channel Interfernce

Freq. (kHz)	BER	BLER	$(E_b/N_o)_{eq}$ (dB-Hz)	Degradation (dB)
250	1.10E-05	0.30%	18.2	-0.3
200	2.60E-05	0.49%	17.8	4.7
190	1.50E-05	0.36%	113.1	-0.4
180	7.15E-05	1.50%	17.3	-12
170	2.38E-04	4.67%	16.7	-1.8
160	3.60E-04	6.90%	16.5	-2.0
150	4.40E-04	8.60%	16.3	-22
140	4.60E-05	0.40%	17.6	-0.9
130	1.50E-05	0.30%	113.1	-0.4
120	1.80E-05	0.42%	18.0	-0.5
110	2.20E-05	0.55%	17.9	-0.6
100	1.20E-04	2.10%	17.1	-1.4
97	4.50E-05	6.10%	17.6	-0.9
95	1.00E-03	13.00%	15.8	-2.7
93	4.50E-03	28.00%	14.6	-3.9
90	1.50E-01	89.00%	9.7	-8.8
80	5.00E-01	100.00%	4.9	-13.6

Figure 3

Estimated Degradation Narrow Band FM



The -10 dB C/I was chosen partly because it was the maximum setting of the test equipment and partly because -10 dB is "reasonable" amount of energy to expect the modem to tolerate from an adjacent channel interferer.

figure 3 shows a plot of the degradation as a function of the interfering carrier offset. From this plot it is apparent that the DSY modem experiences degradation due to an interfering source up to 190 kHz away. However in most cases a 100 kHz carrier spacing would be sufficient. Because of the burst nature of both packet and voice transmission systems the probability that both the interfering carrier and the wanted carrier are on at th8 sam8 time is fairly remote, and a degradation of 3 dB from the nominal used in this test would likely result in a tolerable increase in packet retransmissions. If either the wanted carrier or the interfering source are likely to be on for long periods of time, or very low error rates are required, additional frequency separation of steps to reduce the level Of interference should be taken.

4.2. Co-Frequency Interference

Table 2 shows the resulting $(E_b/N_o)_{eq}$, degradations, BER's and BLER's when the interfering carrier is co-frequency to the wanted carrier and the level of interference is varied.

Table 2
NBFM Co-Channel Interference

C/I (dB)	BER	BLER	E_b/N_{oeq}	Degr.	C/I_{eq}
8	3.70E-02	90.00%	12.3	-6.2	13.5
8	7.30E-03	75.00%	14.2	-4.3	162
10	1.70E-03	26.00%	15.4	-3.1	18.3
12	4.50E-04	7.90%	16.3	-22	203
14	1.60E-04	3.00%	16.9	-1.6	22.0
15	1.00E-04	1.90%	17.2	-1.3	23.1
17	4.50E-05	0.85%	17.6	-0.9	24.9
20	2.30E-05	0.40%	17.9	-0.6	26.8
25	9.10E-06	0.20%	18.3	-0.2	31.8

Figure 4

Degradation Due to Co-Channel NBFM Interference

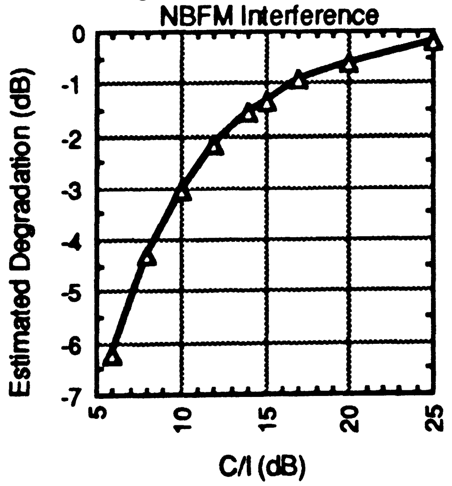


Figure 4 shows a plot of the degradation versus the C/i. The degradation curve is fairly well behaved. However, it is interesting to note that even a C/I of 25 dB causes a slight degradation in performance.

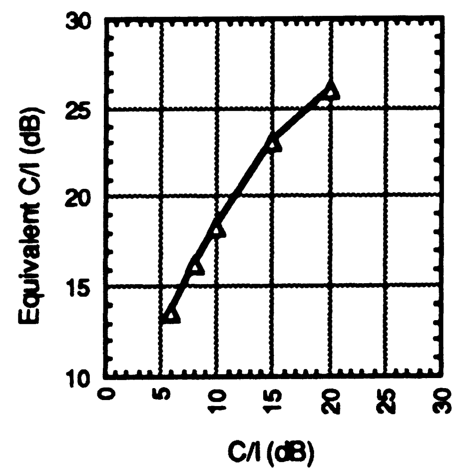
In order to calculate how NBFM will affect the DSY modem at other C/I's and other E_b/N_o 's a means of calculating the "equivalent" CA (C/I_{eq}), of the equivalent noise contribution of the interference, from the actual C/I is required. If the C/I_{eq} is known then it can be added to link budget calculations as another noise source. The C/I_{eq} is determined by calculating the increase in noise required to take the modem from the nominal performance to the BER with interference (the equivalent E_b/N_o).

$$C/I_{eq} = 10^{*} \log[\, 1 / (10^{(-(E_b/N_o)_{eq} / 10)} - 10^{(-E_b/N_o / 10)})]$$

The graph of Figure 5 shows that C/I vs C/I_{eq} is

Figure 5

Co-Channel Interference with NBFM



fairly linear. Closer inspection reveals that C/I_{eq} is approximately equal to C/I plus 8.0 dB. This is not quite what is expected. Although the ratio of the bandwidth of the NBFM to the wide band data is in the order of 8 dB, the interference in the band of the receive signal should affect the entire signal. That is the C/I and C/I_{eq} should be equal. However it appears that the demodulator is quite resistant to narrow band interference.

5. Performance With interfering Wide Band Digital Carriers

5.1. Adjacent Channel Interference

The wide band digital interference test was performed similar to the NBFM case. However, additional C/I's where tested. C/I's Of -3.0 and 0.0 dB were tested to simulate cases of:

. the 0 dB C/I case simulates the outputs from a single site with multi-DSY modem carriers being transmitted with equal levels;

. the -3 dB C/I case simulates the case where adjacent channel input carriers from users are set up so that virtually equal power levels would be received by a multi-channel repeater site;

• the -10 dB C/I case simulates non co-ordinated network with users on adjacent channels transmitting vastly different power levels.

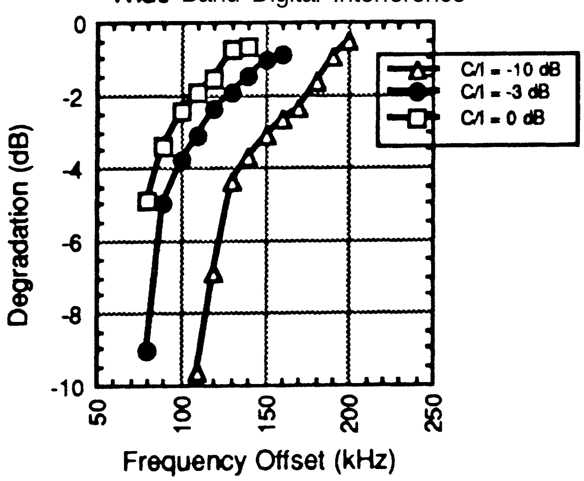
Table 3
Wide Band Data Adjacent Channel Interference
with C/I=-10 dB

Frq. (kHz)	BER	BLER	$(E_b/N_o)_{eq}$ (dB-Hz)	Degradation (dB)
200	1.80E-05	0.42%	18.0	-0.5
190	5.00E-05	1.10%	17.5	-1.0
160	1.70E-04	3.70%	16.9	-1.6
170	5.90E-04	11.00%	162	-2.3
160	1.00E-03	17.00%	15.8	-2.7
150	1.80E-03	23.00%	15.4	-3.1
140	3.66E-03	33.00%	14.0	-3.7
130	7.706-a	68.00%	14.1	-4.4
120	5.70E-02	99.00%	11.6	-6.9
110	2.00E-01	100.00%	8.9	-9.6

Figure 6 shows the plot of frequency versus

Figure 6

Wide Band Digital Interference



degradation. It is clear that in cases where there will be a large difference in received power for closely spaced carriers, that at least 150 kHz spacing should be used. It may be good frequency planning to space the carriers 200 kHz, thus adjacent networks could use the "in between" frequencies without causing interference.

5.2. Co-Channel Wide Band Interference

The final test is with the PSK carrier co-frequency to the DSY modem frequency. The results are given in Table 4.

Table 4
Wide Band Data Co-Channel Interference

C/I (dB)	BER	BLER	$(E_b/N_o)_{eq}$ (dB-Hz)	Degradation (dB)
2	5.00E-01	100.00%	4.9	-13.6
4	1.30E-01	100.00%	10.0	-6.5
6	2.90E-02	99.00%	12.6	-5.9
8	6.90E-03	72.00%	14.2	-4.3
10	1.80E-03	30.00%	15.4	-3.1
12	5.00E-04	10.00%	16.3	-22
15	1.20E-04	2.40%	17.1	-1.4
18	5.80E-05	1.30%	17.4	-1.1
20	3.00E-05	0.64%	17.0	-0.7
25	1.90E-05	0.42%	18.0	-0.5

Figure 7

Degradation Due to a Co-Channel PSK Carrier

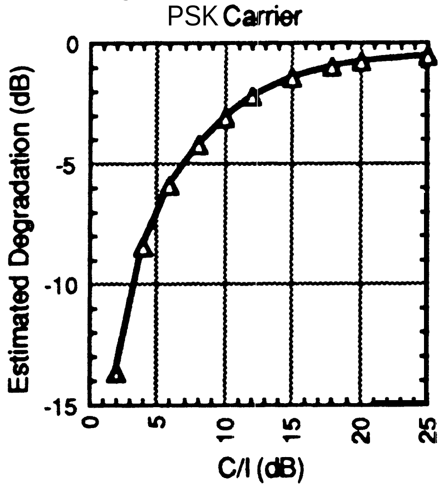
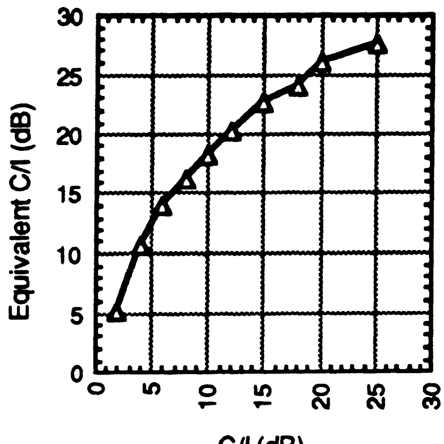


Figure 7 shows the degradation due to the co-channel PSK carrier, In order to achieve a degradation of less that 3 dB there must be at least 10 dB of isolation between networks. However this figure does not tell the whole story.

The result is fairly smooth and it would be expected that the relationship of C/I to C/I_{eq} would be linear and one to one. However as seen in Figure 8 the C/I_{eq} is better than the C/I by up to 8 dB. This is unexpected. Because a wide band noise like signal is placed co-frequency to the data signal it is expected that the degradation would be

Figure 8

Co-Channel Wide Band Data Interference



dB for dB. However, it may be explained that:

1) the MSK receive characteristics have fairly significant sidelobes (as seen at 150 kHz offset in Figure 3),

2) the PSK interference spectrum does not have sidelobes that interfere with the MSK sidelobes,

3) the MSK modem may be receiving a significant amount of information from the sidelobes,

thus allowing better performance than expected.

For use in coordinating networks it is recommended that interference allocations be based on the actual C/I with corrections for the difference in occupied bandwidths. Using this allocation there would be some margin. Note, however, if the IF filtering is improved for adjacent channel rejection, co-channel interference performance would most likely suffer (this would be an interesting topic of future tests).

6. Recommendations and Conclusions

The results presented in this paper will be useful tools for wide band digital carrier users in co-ordinating networks with:

- other wide band digital networks;
- NBFM packet networks; and,
- NBFM repeaters.

It is recommended that general coverage repeaters sites using multiple standard DSY modems should maintain a channel spacing of 150 kHz or more. Actual degradations or noise contributions due to interference may be taken from Figure 6 and Table 3. However, by modifying the receive filtering of the modem it may be possible to reduce the adjacent channel interference so that 100 kHz spacing may be used.

It is recommended that networks using DSY modems should maintain a minimum separation of 100 kHz to the nearest NBFM carrier. Again actual degradations and noise contributions can be taken from Figure 2 and Table 1.

For frequency reuse and co-frequency interference, the amount of isolation required should be based on the traffic mix:

. for common user repeaters and cases where high reliability is desired: link budgets should be calculated with a noise allocation for interference, if the interference is NBFM the C/I allocation should be 8 dB better than the actual C/I, if the interference is wide band data of another DSY modem carrier a noise allocation equivalent to the C/I should be added;

. for applications where high reliability is not required of where the probability of Carrier and Interference being on at the same time is small: the C/I should be at least 10 dB.

References:

[1] Heatherington, D., "A 56 kilobaud RF modem", Sixth ARRL Computer Networking Conference, Redondo Beach, CA, August 27, 1987, pp. 68-75.

[2] McLarnon, B., "The 56 kb/s Modem as a Network Building Block: Some Design Condiderations", Tenth ARRL Computer Networking Conference