IEEE 802.11
Wireless Access Method and Physical Layer Specifications

Title: Interference Immunity Measurements on a 2-Level CPFSK Transceiver

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1.0 Introduction

The purpose of this submission is to provide the committee with additional data and information about the performance of two-level continuous phase frequency shift-keyed modulation (2-CPFSK) as a function of adjacent, alternate and co-channel interference rejection. The measurements were made on a 2.4 GHz Frequency Hopping (FH) radio transceiver designed to operate in a 1.0 MHz wide channel bandwidth.

2.0 Adjacent and Alternate Channel Interference Immunity

2.1.0 Measurement Procedure

The following setup was used to measure the adjacent (+/- 1.0 MHz) and alternate (+/- 2.0 MHz) channel rejection performance of the current radio transceiver with modulated (wideband) and CW (narrowband) interferers. This was measured on two (2) different units at opposite ends of the frequency band. The chosen frequencies, F_o, were 2.41 GHz and 2.47 GHz, and the receiver input level at a BER of $1x10^{-5}$ was set at -80 dBm. Additional measurements were made at -50 dBm. This measurement will give information pertaining to the ability to Co-Locate LAN's in the same geographic vicinity. The following test conditions applied to all measurements:

Transmitter: S/N 007 set to +10 dBm power output
Signal Gen: Modulation parameters:
Fmod = 312.5 kHz
Fdev = 375 kHz
Receiver: Radio transceivers S/N's 006 & 008
Analyzers:
FireBERD Clock Generator = 625 kHz
Block Length = 100,000 bits
Number of Blocks = 100
PRN code length = $2^{15} - 1$
Clock Recovery option on receiver's FireBERD
Spectrum Analyzer RBW = VBW = 100 kHz
Span = 1 - 10 MHz

System calibration was performed to determine the cable losses and actual output power of the transmitter. These results were used to calibrate the path loss of the transceiver pair. The wanted carrier level was set by injecting the spectrum analyzer, which replaces the receiver in the system diagram, with a CW source at the desired frequency and varying the attenuation until the correct received power level was attained. The interfering transmitter is disabled during this calibration process.

2.1.1 Analysis

The co-location of LAN's in the same geographic area can be analyzed by the adjacent (F_o + 1 channel above or below) and alternate (F_o + 2 channels above or below) channel rejection of the receiver. This performance affects the ability of the LAN to operate at a BER < $1x10^{-5}$ in the vicinity of a similar LAN (referred to as a wideband interferer) or a narrowband interferer that is located 1 or 2 channels away from the intended receiver.

From the data, it is clear that the overall performance of the receiver is better under narrowband conditions. When the receiver is subjected to a CW interference source, the alternate channel rejection is 34-38 dB, as compared to 20-24 dB for a wideband or modulated source. In terms of the adjacent channel rejection, there is no difference between the two interference sources. These transceivers do not give sufficient adjacent channel rejection, which means that the hopping sequences will need to be carefully selected in order to optimize the performance of the system.

After further investigation of the system parameters, it was determined that the current transceiver design had a limitation on the alternate channel rejection. The first IF amplifier was saturating and causing desensitization of the receiver by the unwanted signal. This can be understood by the following table:

(A) Conversion gain of frontend:	22 dB
(B) 350 MHz SAW rejection @ +/- 1.5 MHz:	21 dB
(C) SL6444 gain:	17 dB
(D) 1st IF amplifier gain:	20 dB
(E) 350 MHz SAW Insertion Loss:	10 dB

If the scenario was:

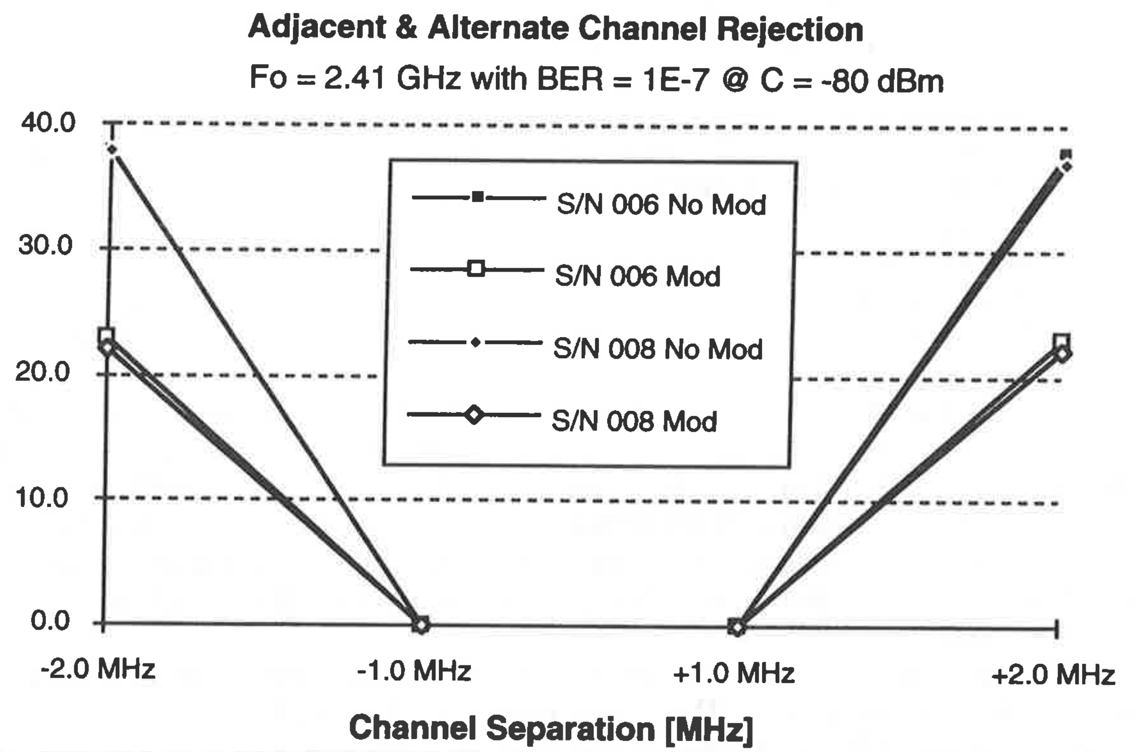
Unwanted Tx @ +/- 2.0 MHz 1.0 meter away: (40 dB path loss at 1.0 meter)	-20 dBm
After point (A):	2.0 dBm
After SAW filter (B & E):	-29 dBm
After point (C):	-12 dBm
After point (D):	8.0 dBm

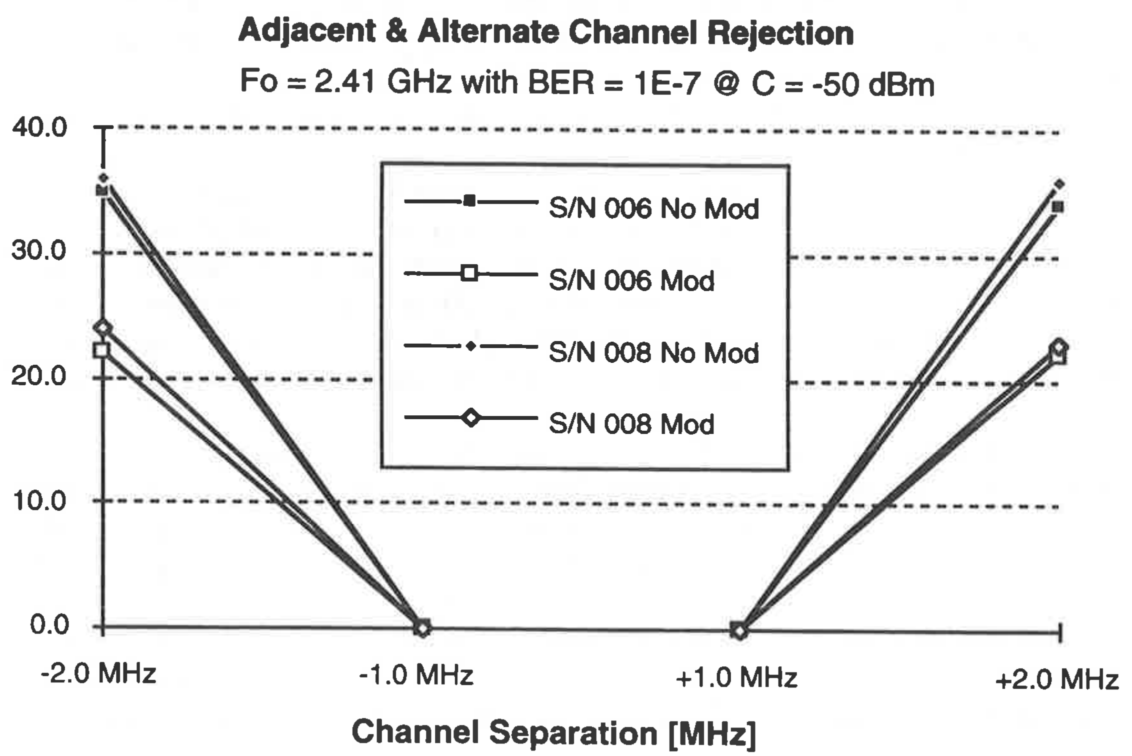
From the above result, and noting that the output compression point of the first IF amplifier is 3.0 dBm, we can see that this device is in compression. If the unwanted signal level is reduced by about 10 dB, the receiver will function correctly. This limitation will not affect the final design, as the gain distribution and filter skirts are designed correctly. In fact, the predicted alternate channel rejection for the final transceiver design is on the order of 47 dB, a 13 dB improvement.

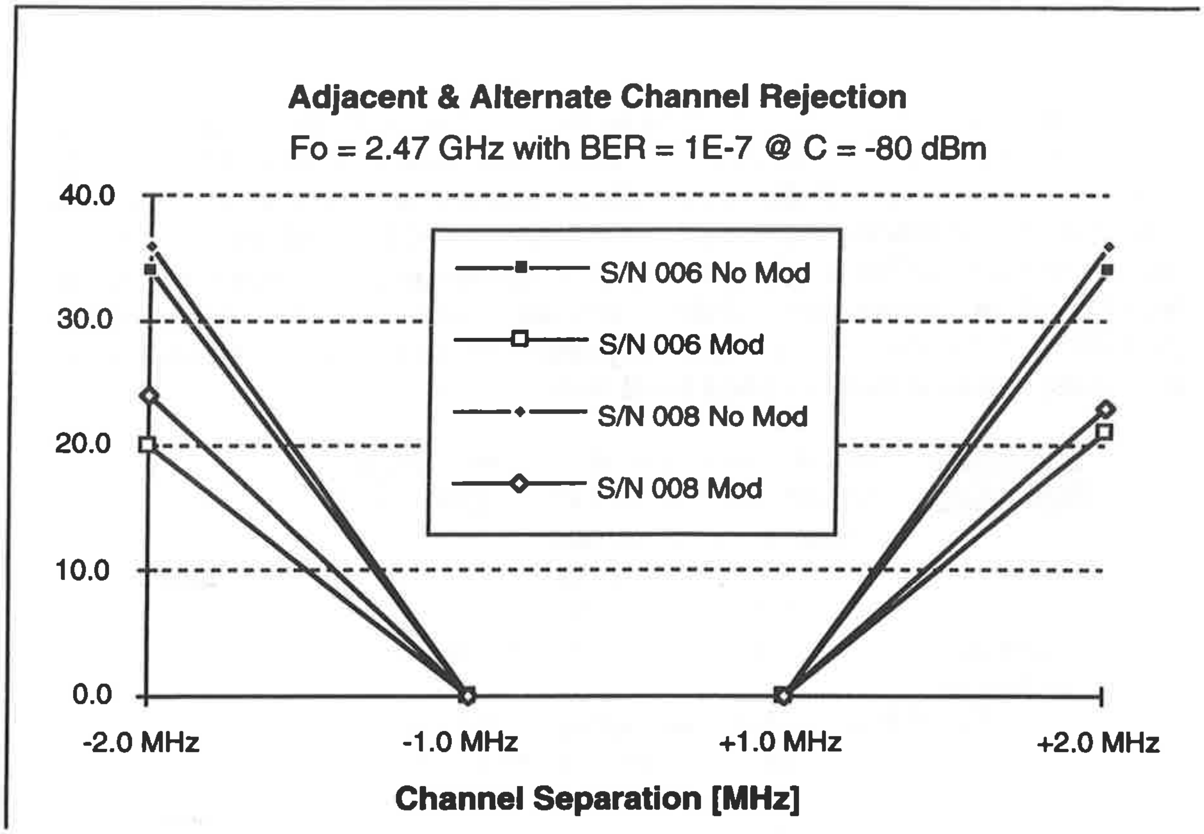
In general, there are two factors that limit the alternate channel rejection performance of the receiver. These are the passband filter skirts and local oscillator phase noise. As far as the skirts are concerned, the final implementation will have > 30 dB rejection for the 350 MHz and 38 MHz SAW's at +/- 1.5 MHz from the center of the passband. This should provide the required 60 dB rejection at the band edge of the upper and lower alternate channels. For the phase noise performance, the design value of -130 dBc/Hz corresponds to -68 dBc/Hz in a 1.5 MHz bandwidth (10log[1.5 MHz]), the value of the receiver passband. If we use the required C/I of 13 dB for the wideband interference case, the maximum interference signal level that the system can withstand is around -55 dBm. Therefore, the filter rejection and phase noise performance collapse at about the same value, with the phase noise being the limiting factor. If we look at the narrowband C/I of 5 dB, then this level moves to -63 dBm and the limitation shifts to the filter skirts. Additional measurement data on the final radio transceiver design will be available at the September meeting.

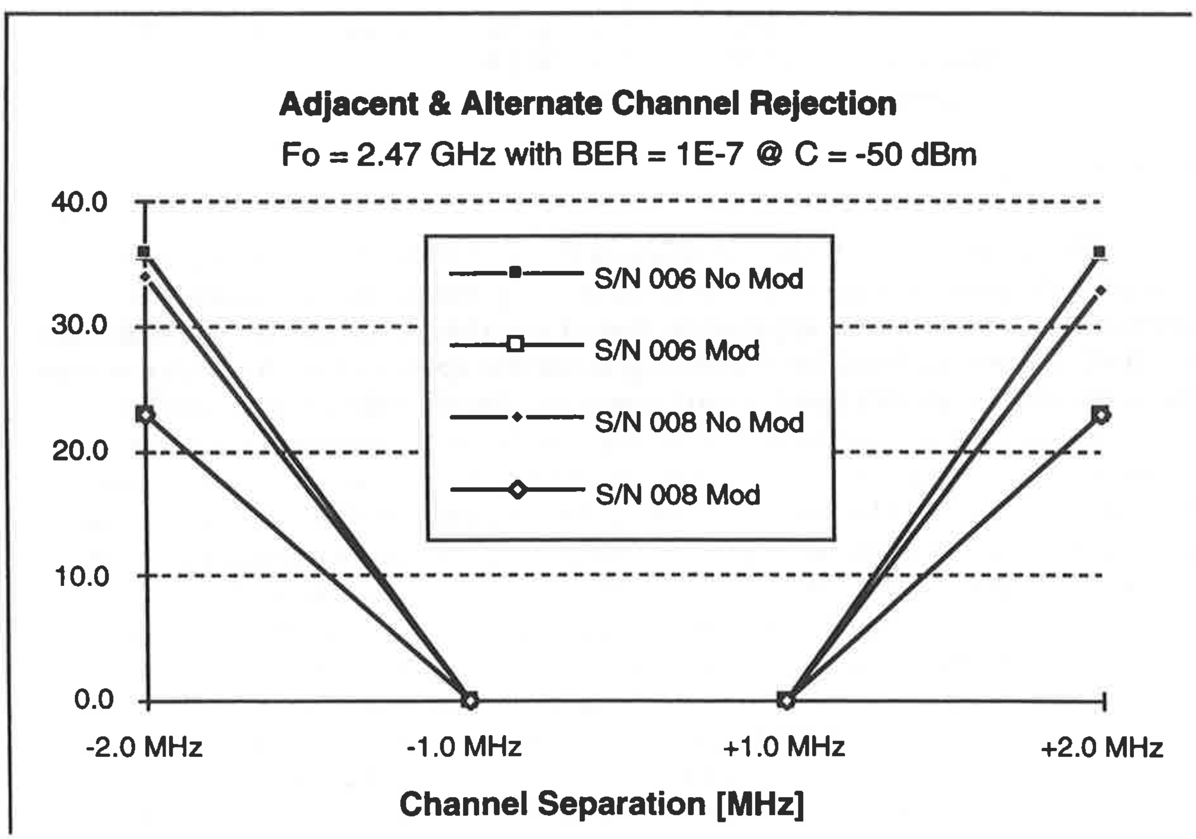
As for the wideband interference case, the current radio transceiver implementation is about 15 dB worse than the narrowband case. This will have a direct effect on the operation of our LAN in the presence of like systems in the same frequency domain. The intended final implementation, although it will improve the wideband rejection, will probably not meet our design goal of 60 dB alternate channel rejection for the wideband case. It should be noted that this specification will not cause the LAN to stop working. Instead, it will cause degradation to the dynamic range and overall performance of our transceiver system.

2.1.2 Selectivity versus Sensitivity versus Frequency






Adjacent & Alternate Channel Rejection
Fo = 2.47 GHz with BER = 1E-7 @ C = -80 dBm
40.0
30.0
20.0
10.0
0.0
S/N 006 No Mod
S/N 006 Mod
S/N 008 No Mod
S/N 008 Mod
-2.0 MHz
-1.0 MHz
+1.0 MHz
+2.0 MHz
Channel Separation [MHz]


Adjacent & Alternate Channel Rejection
Fo = 2.47 GHz with BER = 1E-7 @ C = -50 dBm
40.0
30.0
20.0
10.0
0.0
S/N 006 No Mod
S/N 006 Mod
S/N 008 No Mod
S/N 008 Mod
-2.0 MHz
-1.0 MHz
+1.0 MHz
+2.0 MHz
Channel Separation [MHz]

3.0 Co-Channel Interference Immunity

3.1.0 Measurement Procedure

The following setup was used to measure the BER (Bit Error Rate) versus Carrier-to-Interference ratio (C/I) of the current transreceiver architecture. This was measured on two (2) different units at opposite ends of the frequency band. The chosen frequencies, F_o, were 2.40 GHz and 2.48 GHz, and the receiver input level at $1x10^{-5}$ BER was -80 dBm. Additional measurements were made at input levels of -50 dBm and -30 dBm. This measurement will give information pertaining to the Co-Channel rejection performance of the transceiver. The following test conditions applied to all measurements:

<u>Transmitter:</u> S/N 007 set to +10 dBm power output
<u>Signal Gen.:</u> R/S 385.8011.52 (100 kHz - 4320 MHz)
Modulation parameters:
Fmod = 312.5 kHz
Fdev = 375 kHz
<u>Receiver:</u> Radio transceivers S/N's 008 & 009
<u>Analyzers:</u>
FireBERD: Clock Generator = 625 kHz
Block Length = 100,000 bits
Number of Blocks = 100
PRN code length = $2^{15} - 1$
Clock Recovery option on receiver's FireBERD
Spectrum Analyzer: RBW = VBW = 100 kHz
Span = 1 - 10 MHz

3.1.1 Analysis

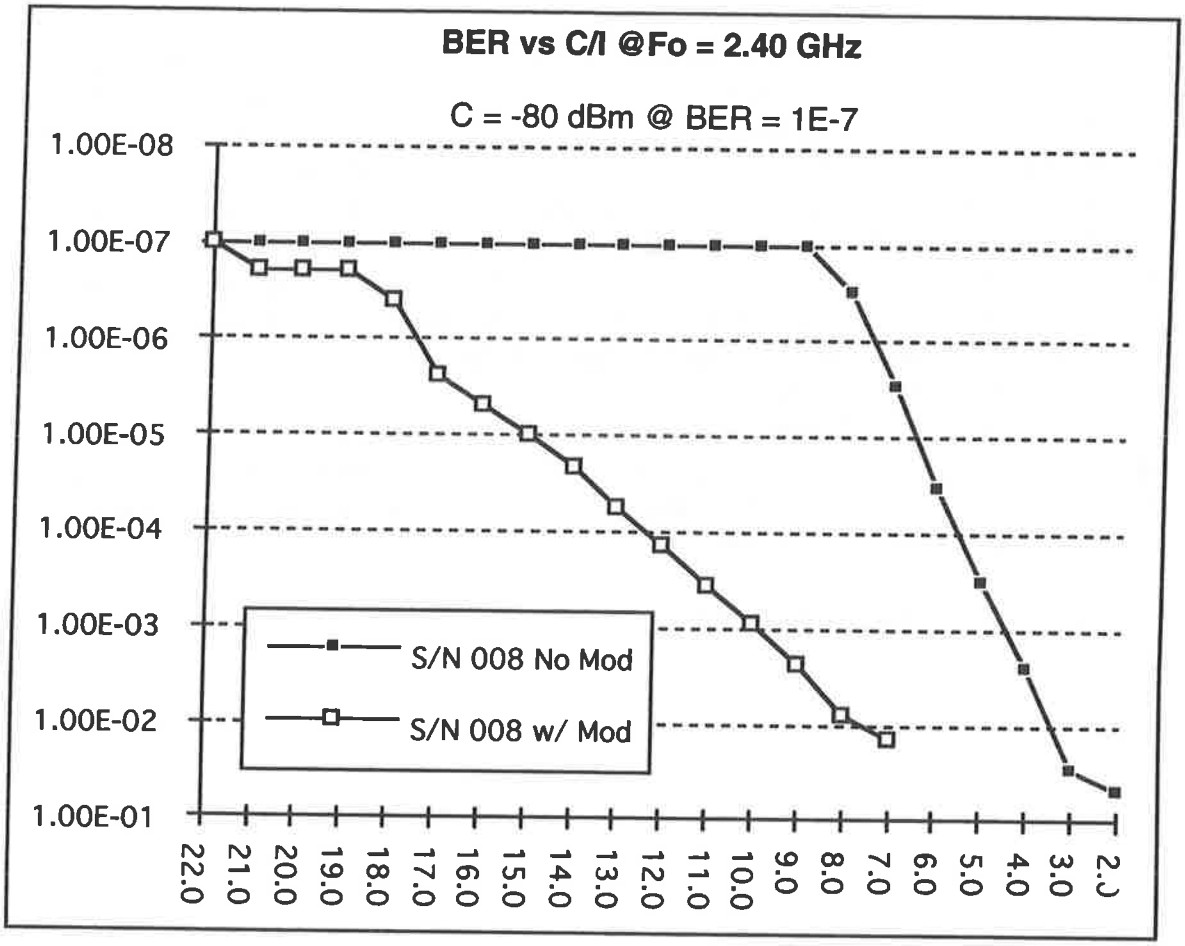
There are two things to compare in this test. First, it will be interesting to compare the performance of the receiver in the presence of a narrowband interferer (no modulation applied) to that of a wideband interferer (modulation applied). Secondly, it will be interesting to see the spread of performance across the operating frequency band, input sensitivity levels and between similar units.

In the case of a narrowband versus a wideband interference source, it can be seen that the receiver can withstand more interference or power from the narrowband source. This makes sense as the limiting amplifier in the IF chain in the presence of a modulated signal would be more prone to mixing products causing distortion to the data stream in the IF or baseband signal. Whereas, the narrowband or CW signal will begin to cause distortion when its power level reaches a point that exceeds the capture ratio of the targeted transceiver.

From the data, it appears that the capture ratio of a narrowband signal is on the order of 4-6 dB at 2400 MHz and increases to 6-8 dB at 2480 MHz. However, for the wideband or modulated signal, the capture ratio increases to 12-15 dB at 2400 MHz and 13-17 dB at 2480 MHz, an increase in wanted signal level on the order of 9 dB. This equates to increasing the transmitter power or improving the receiver sensitivity by a factor of eight. This means that in the presence of other LAN systems with similar modulation schemes or wideband interference sources, we will not be able to handle as high of a level of interference before the system begins to degrade, as compared to a narrowband or CW source. The above mentioned data was referenced to a BER of 1.0×10^{-5} and covers the input sensitivity range of -80 dBm to -30 dBm. In general, the capture ratio decreases by about 2.0 dB as the input signal level changes from -80 dBm to -30 dBm. This is related to the fact that the desired signal is considerably stronger at -30 dBm.

If we let the BER increase to between 1.0×10^{-3} to 1.0×10^{-2}, then our capture ratio decreases by about 2-3 dB and 5-7 dB for the unmodulated and modulated cases, respectively. Again, this will enhance our overall dynamic range and system performance.

3.1.3 BER versus C/ I versus Sensitivity


BER vs C/I @Fo = 2.40 GHz
C = -80 dBm @ BER = 1E-7
1.00E-08
1.00E-07
1.00E-06
1.00E-05
1.00E-04
1.00E-03
1.00E-02
1.00E-01
S/N 008 No Mod
S/N 008 w/ Mod
22.0
21.0
20.0
19.0
18.0
17.0
16.0
15.0
14.0
13.0
12.0
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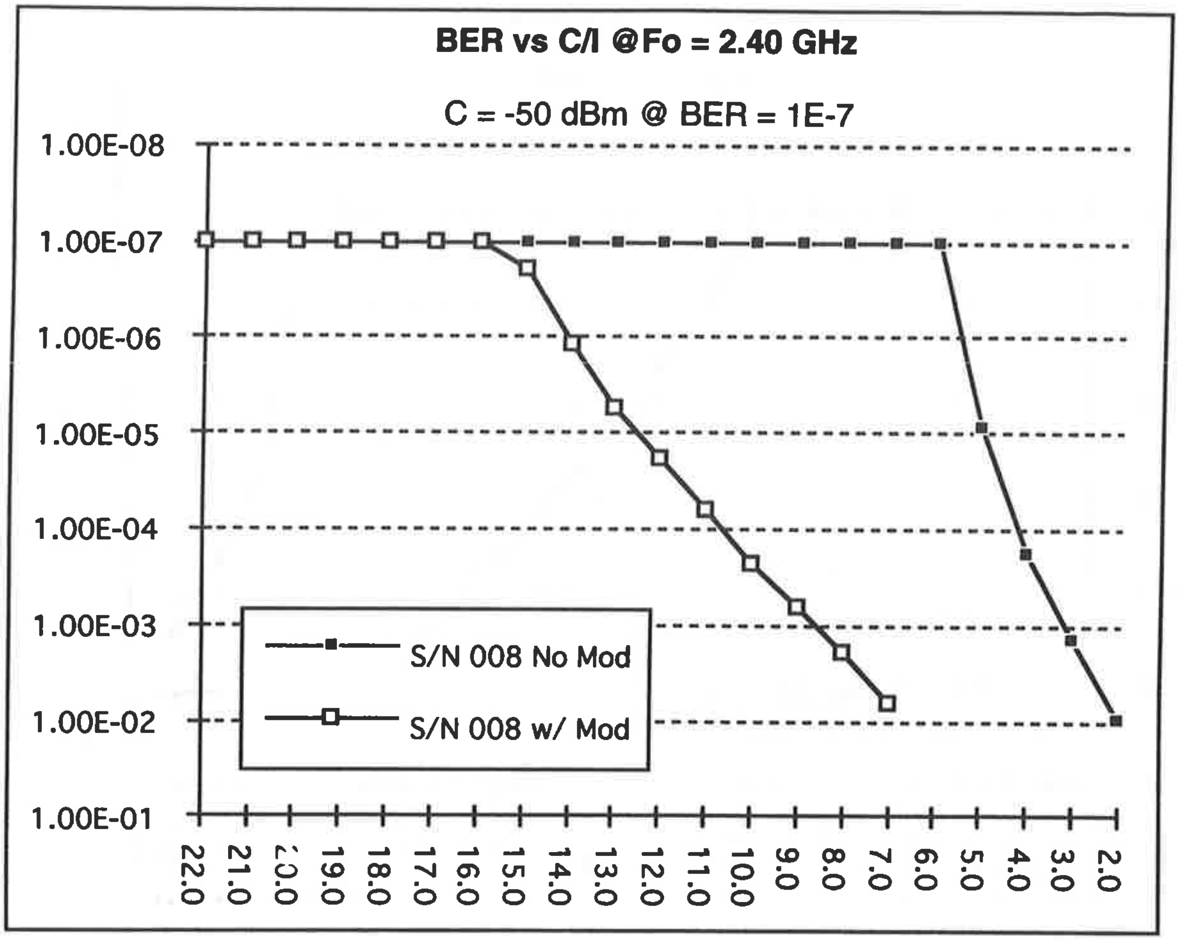
5.0
4.0
3.0


BER vs C/I @Fo = 2.40 GHz
C = -50 dBm @ BER = 1E-7
1.00E-08
1.00E-07
1.00E-06
1.00E-05
1.00E-04
1.00E-03
1.00E-02
1.00E-01
S/N 008 No Mod
S/N 008 w/ Mod
22.0
21.0
19.0
18.0
17.0
16.0
15.0
14.0
13.0
12.0
11.0
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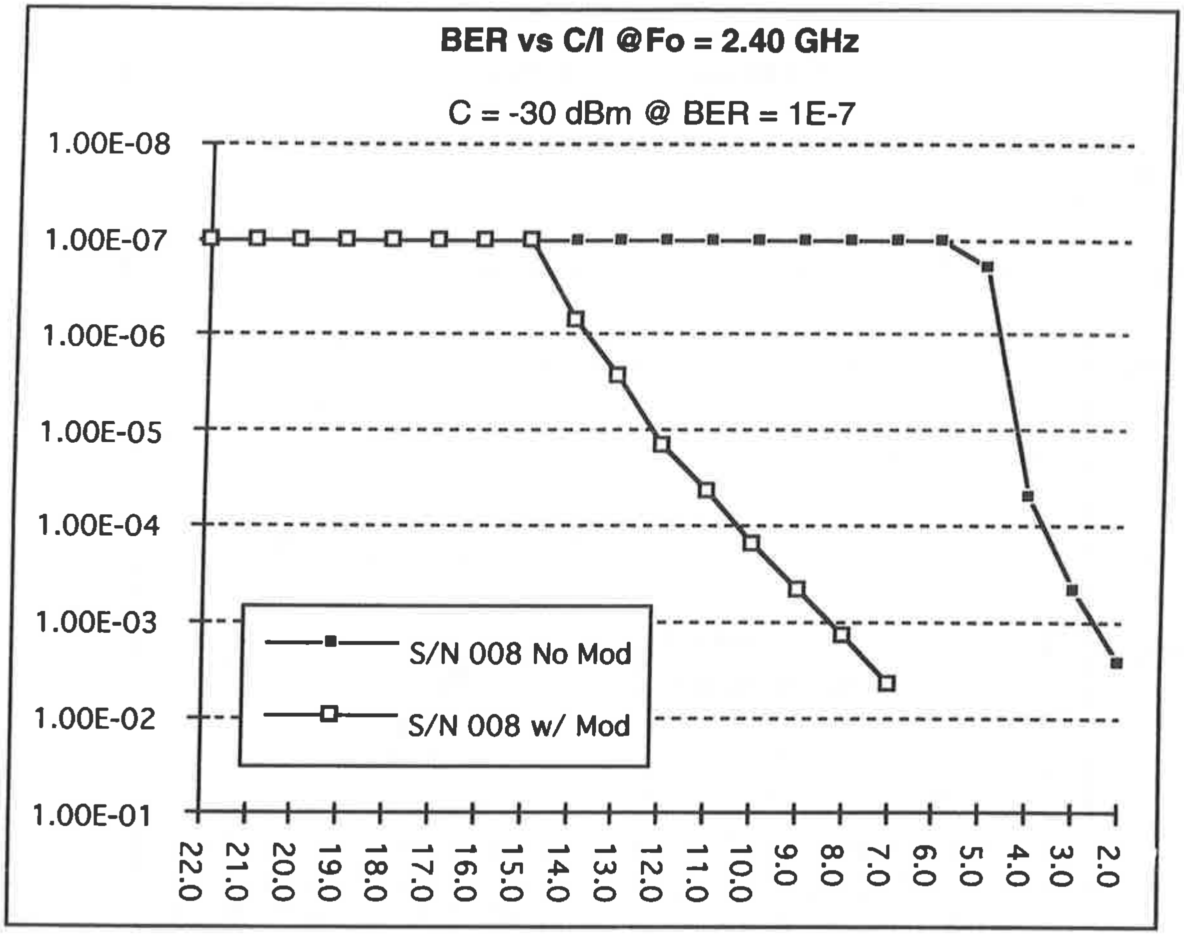
4.0
3.0
2.0


BER vs C/I @Fo = 2.40 GHz
C = -30 dBm @ BER = 1E-7
1.00E-08
1.00E-07
1.00E-06
1.00E-05
1.00E-04
1.00E-03
1.00E-02
1.00E-01
S/N 008 No Mod
S/N 008 w/ Mod
22.0
21.0
20.0
19.0
18.0
17.0
16.0
15.0
14.0
13.0
12.0
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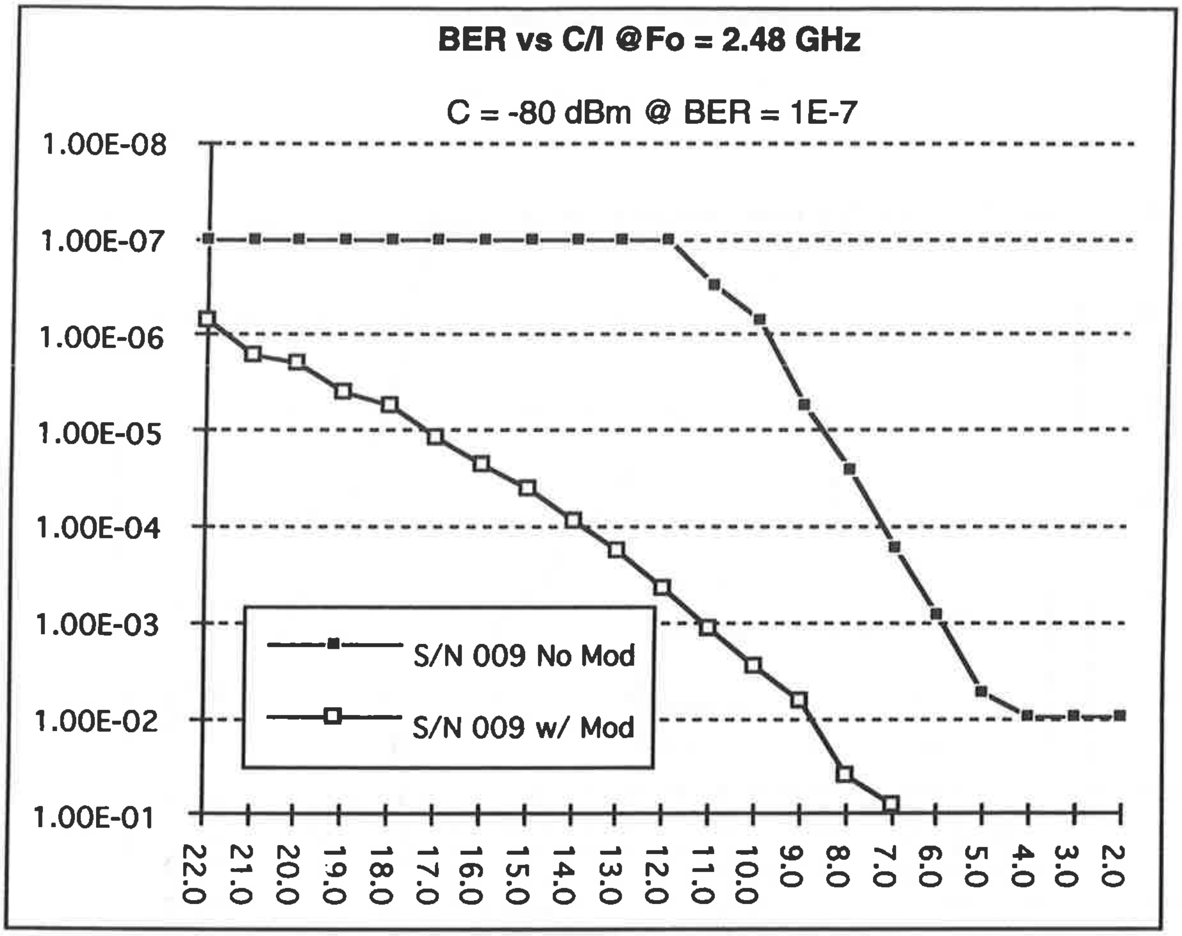
4.0
3.0
2.0


BER vs C/I @Fo = 2.48 GHz
C = -80 dBm @ BER = 1E-7
1.00E-08
1.00E-07
1.00E-06
1.00E-05
1.00E-04
1.00E-03
1.00E-02
1.00E-01
S/N 009 No Mod
S/N 009 w/ Mod
22.0
21.0
20.0
19.0
18.0
17.0
16.0
15.0
14.0
13.0
12.0
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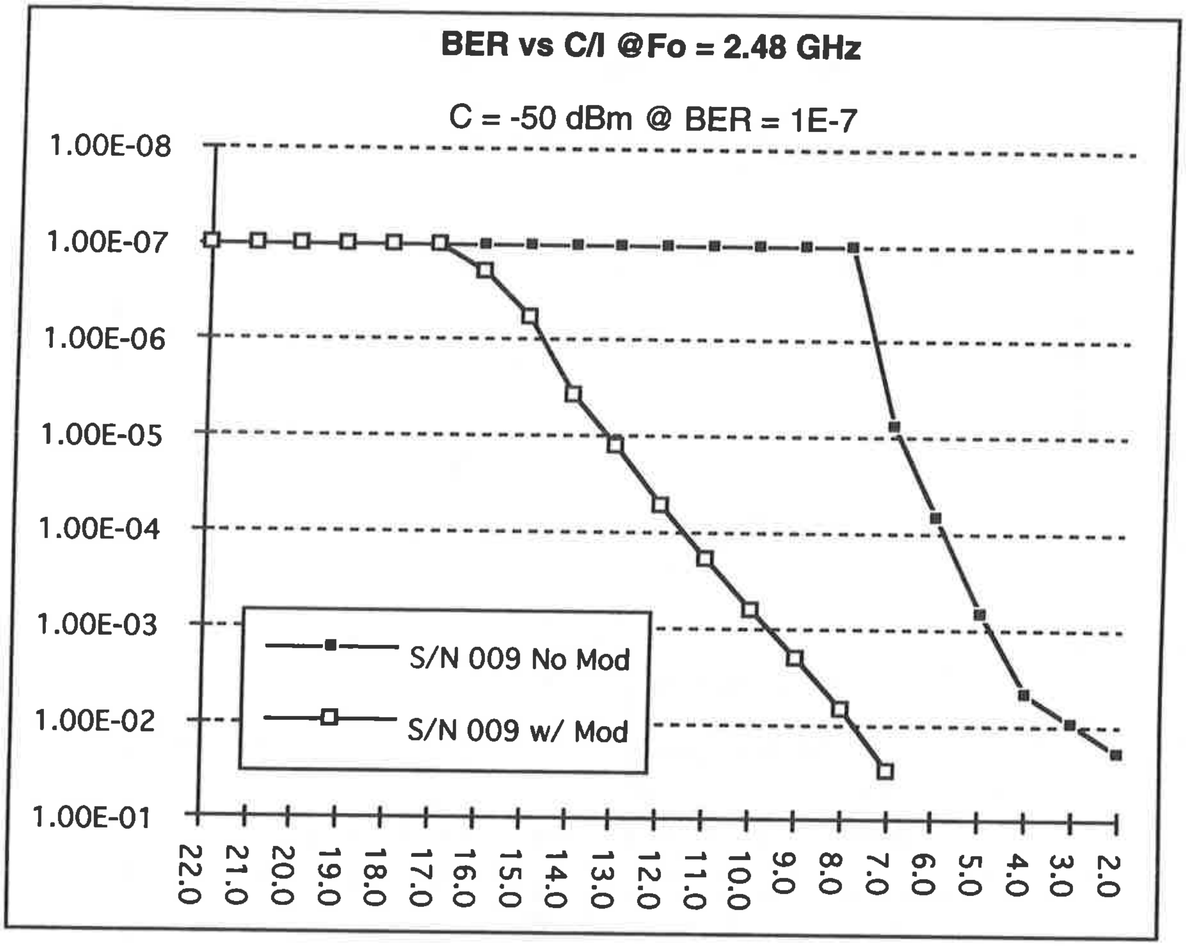
4.0
3.0
2.0



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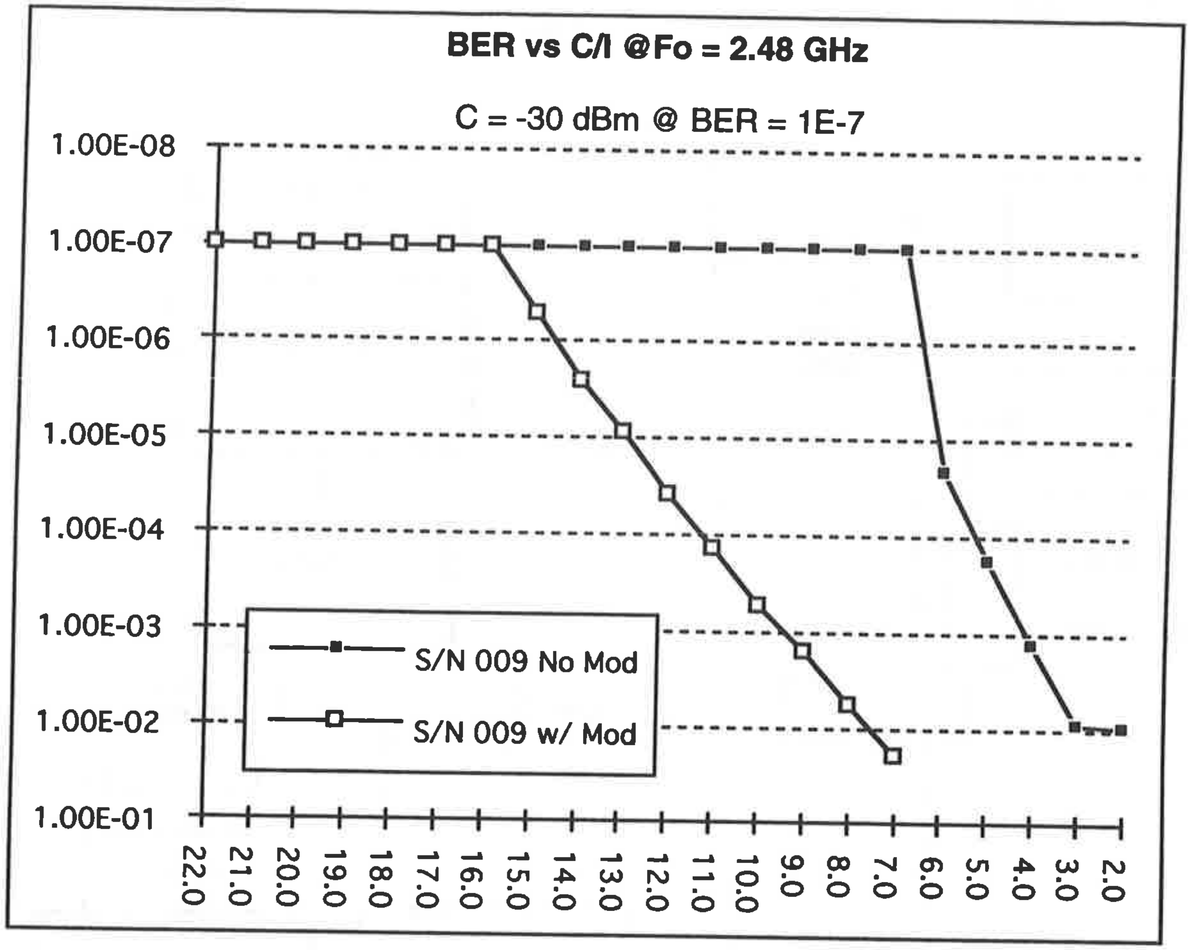
BER vs C/I @Fo = 2.48 GHz
C = -30 dBm @ BER = 1E-7
1.00E-08
1.00E-07
1.00E-06
1.00E-05
1.00E-04
1.00E-03
1.00E-02
1.00E-01
S/N 009 No Mod
S/N 009 w/ Mod
22.0 21.0 20.0 19.0 18.0 17.0 16.0 15.0 14.0 13.0 12.0 11.0 10.0 9.0 8.0 7.0 6.0 5.0 4.0 3.0 2.0

4.0 System Setup