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Measurements on the PC-module

20dB bandwidth plots:

Following 3 plots show the 20dB channel bandwidth at the lowest channel, mid channel and the highest channel.

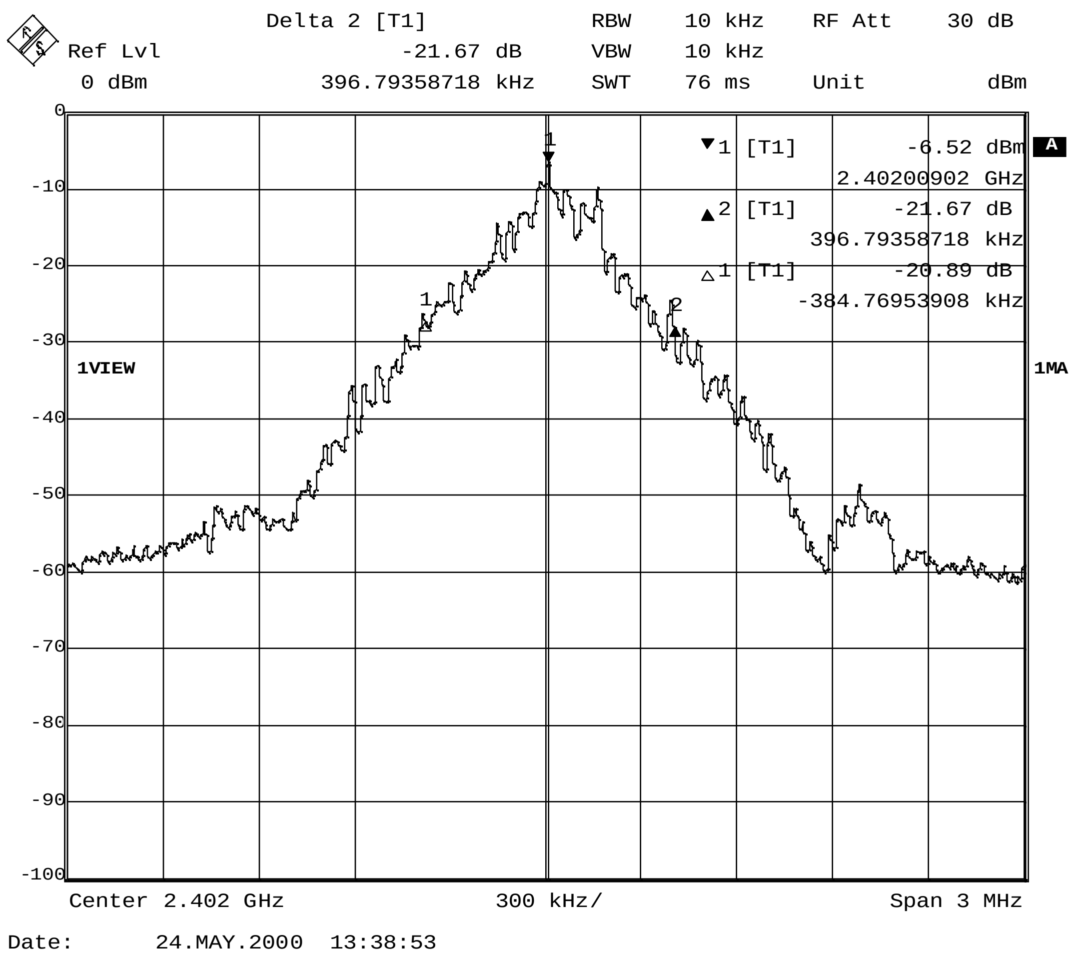

Figure 1: 20 dB bandwidth channel 2 (active mode)

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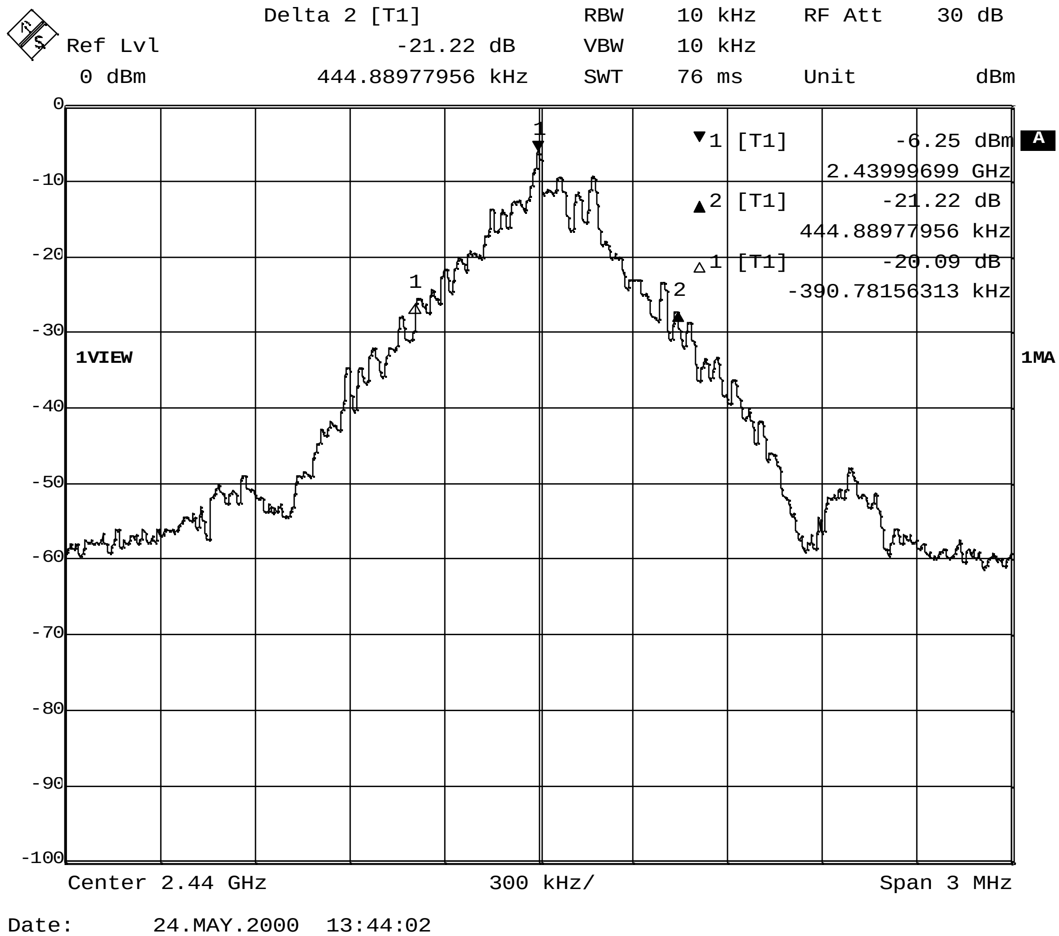

Figure 2: 20 dB bandwidth channel 40 (active mode)

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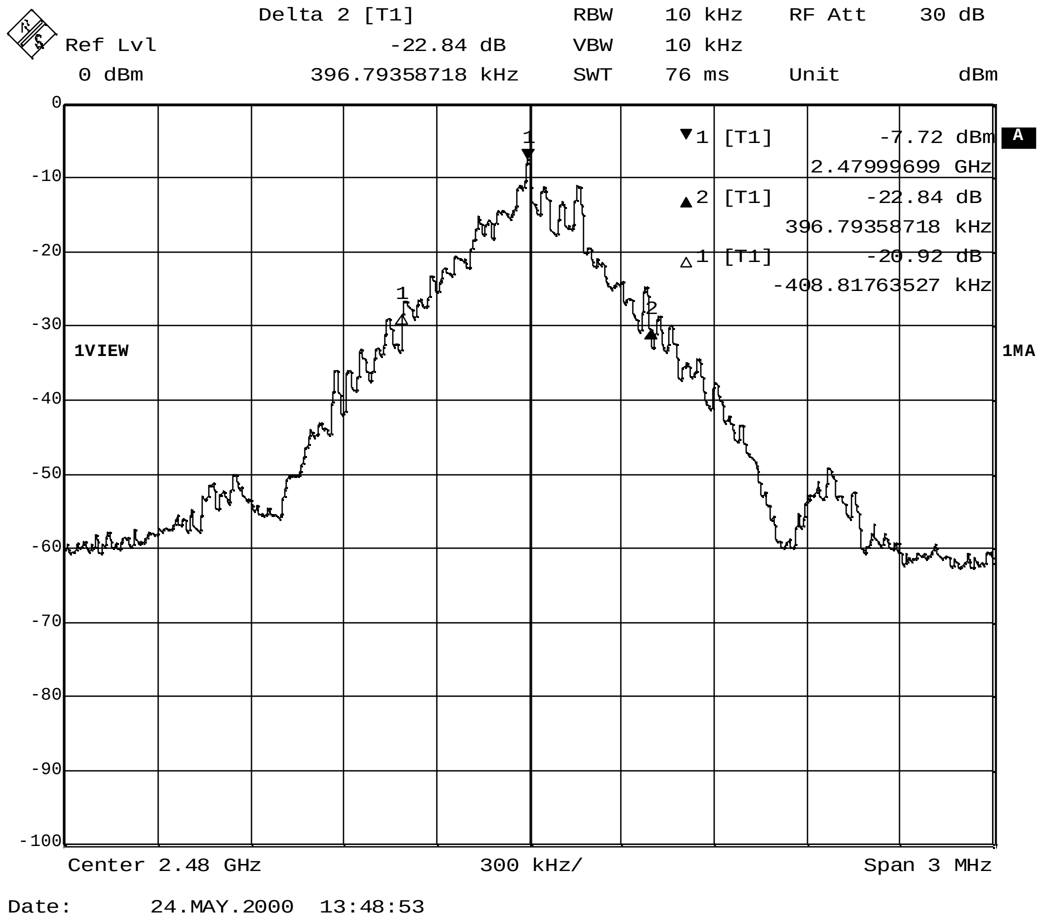

Figure 3: 20 dB bandwidth channel 80 (active mode)

Dwell time plots

To show the dwell times 3 plots are made for both page mode and inquiry mode. The 13 second time frame shows the number of blocks of activity on a channel. The 100ms plot shows the number of multiple transmissions in one block. The 300us plot shows the time period of one transmission. From these plots it is easy to derive that the dwell time is within the FCC requirements.

Page mode:

There are 5 blocks of 1.28 sec in the first plot (figure 4). In the plot of figure 5 it can be seen that every 10 msec there is a transmission. That means that in the time of 12.8 sec there are 5 (blocks)* 128 (transmissions per block) = 640 transmissions.
Every transmission lasts 182 usec. (see figure 6) So the active time on a channel is: 640*182u = 116.5 ms. This is well within the spec of 400msec max.

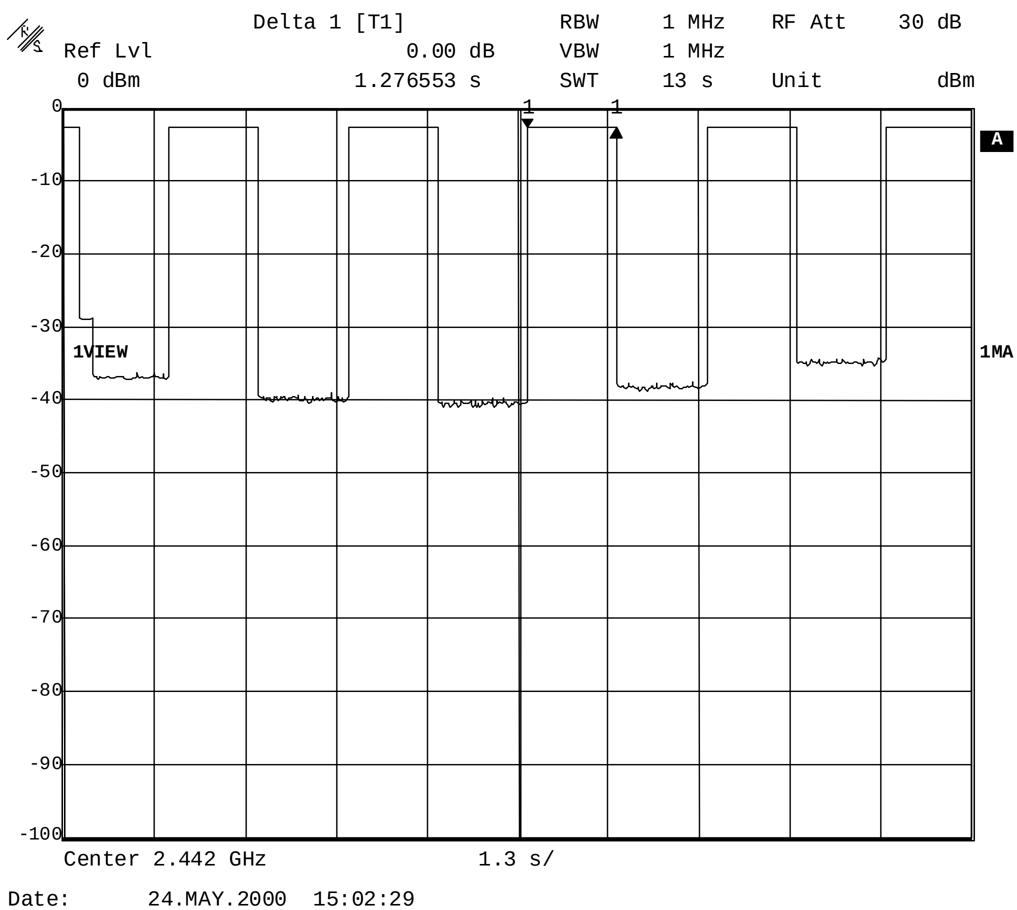

Figure 4: 13 second plot of activity on one channel in page mode

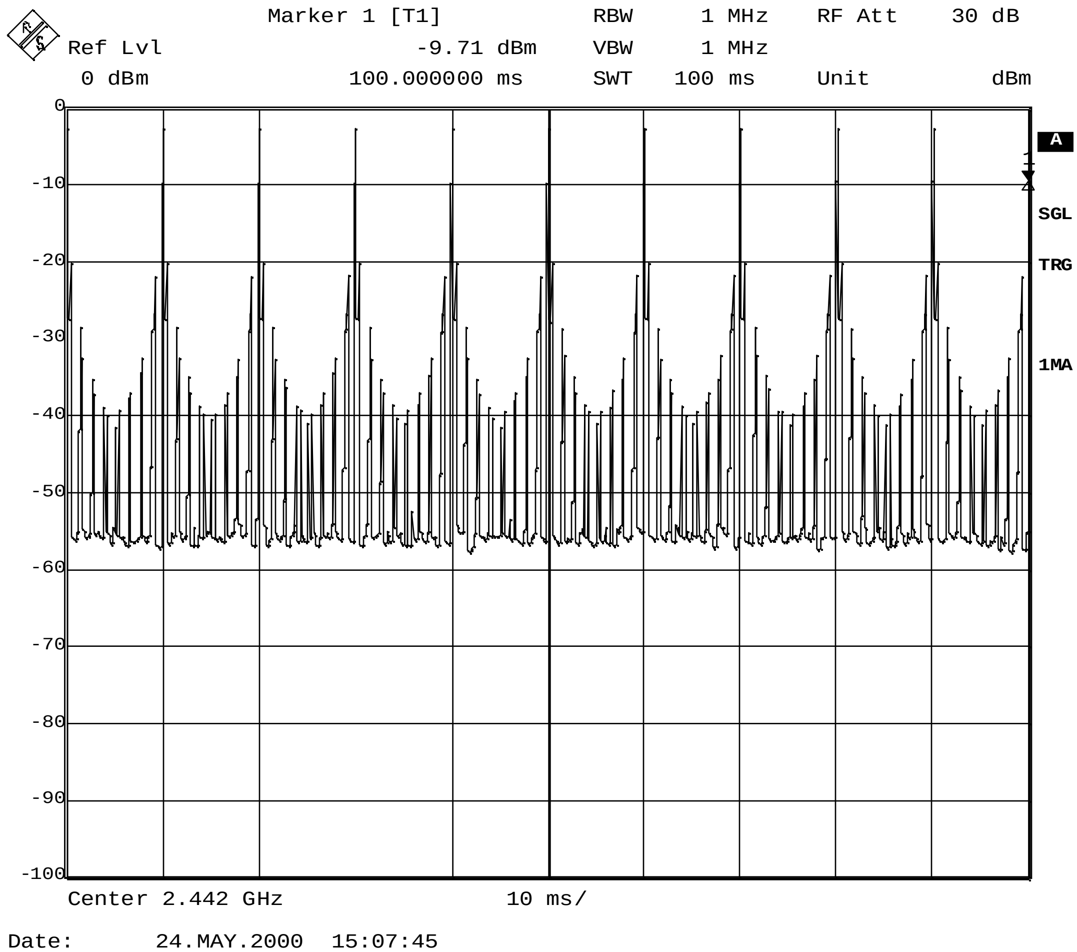

Figure 5: 100 millisecond plot of activity on one channel in page mode

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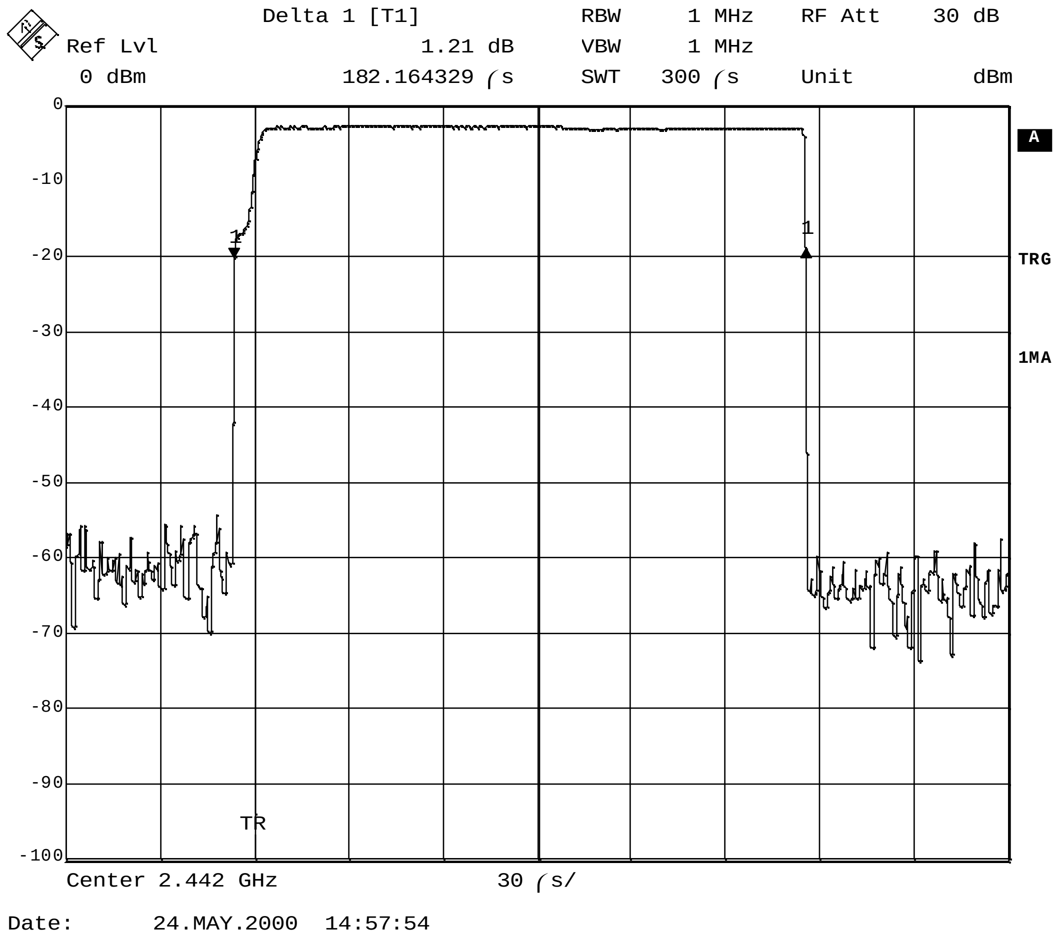

Figure 6: 300 microsecond plot of activity on one channel in page mode

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Inquiry mode:

There are 2 blocks of 2.56 sec in the first plot (figure 7). In the plot of figure 8 it can be seen that every 10 msec there is a transmission. That means that in the time of 12.8 sec there are 2 (blocks)* 256 (transmissions per block) = 512 transmissions.
Every transmission lasts 182 usec. (figure 9) So the active time on a channel is: 512*182u = 98.3 ms. This is well within the spec of 400msec max.

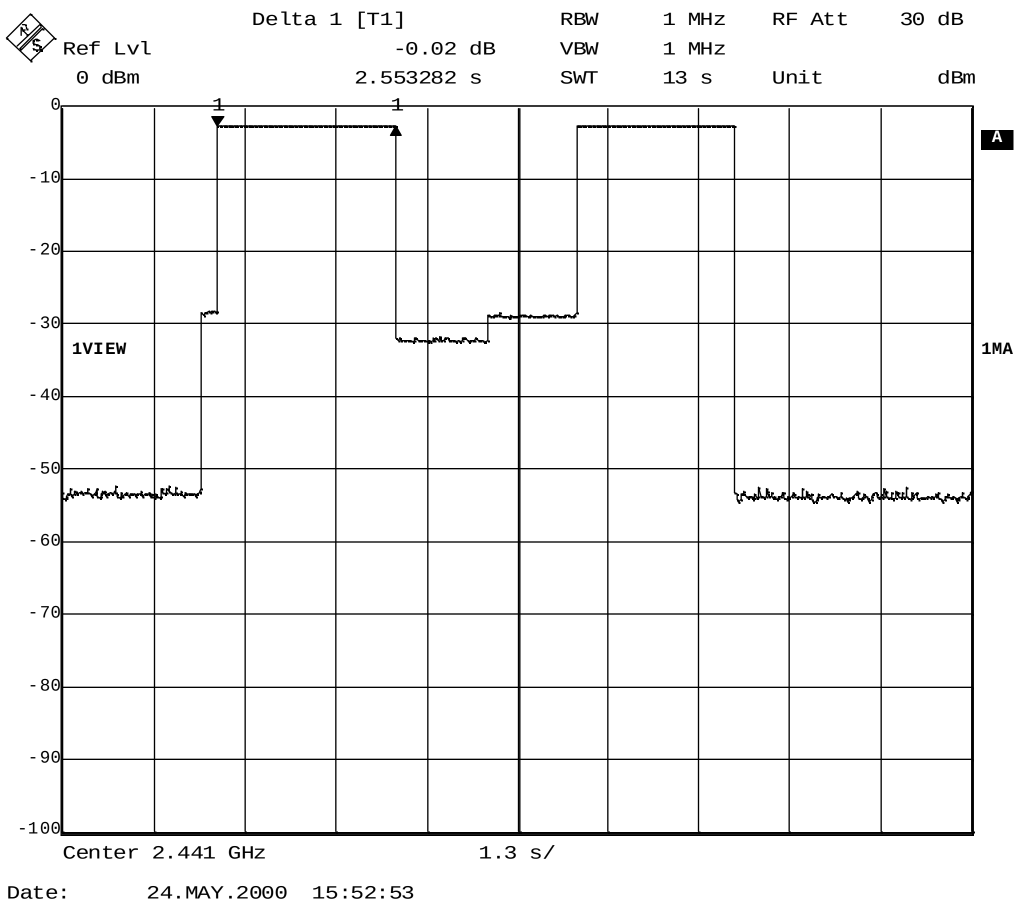

Figure 7: 13 second plot of activity on one channel in inquiry mode

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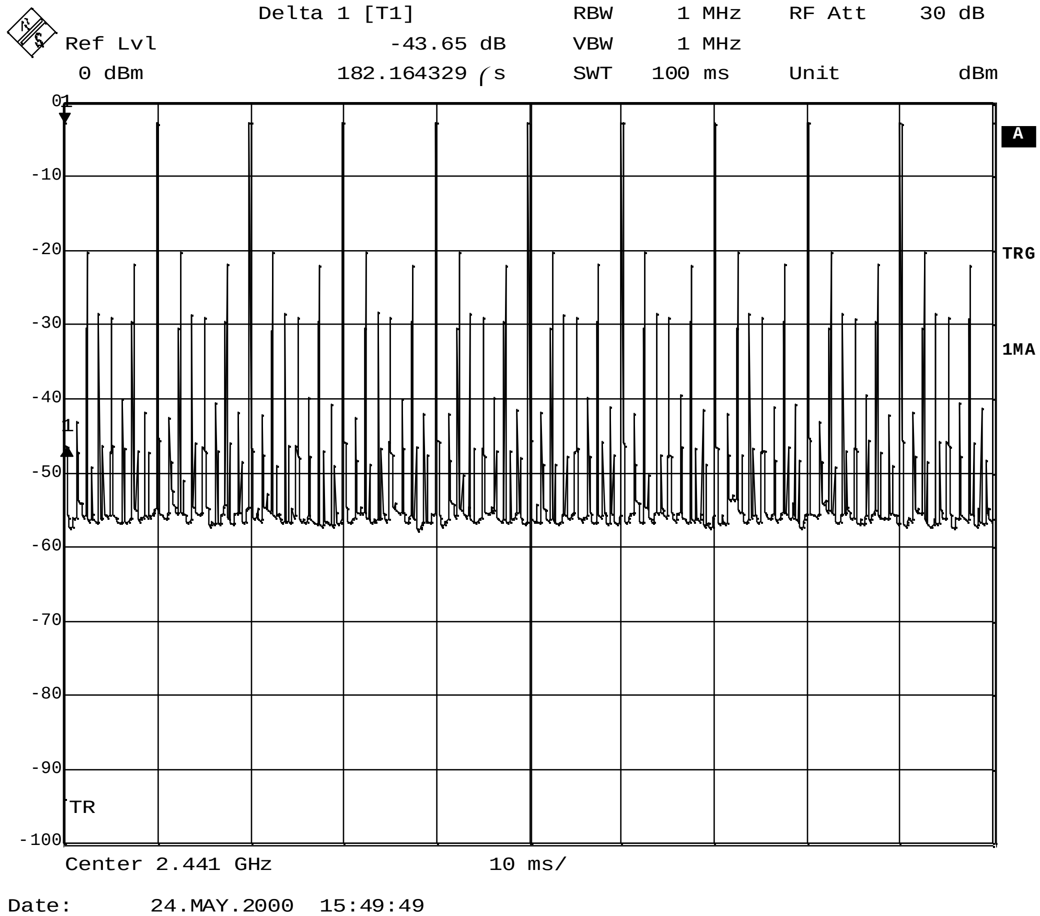

Figure 8: 100 millisecond plot of activity on one channel in inquiry mode

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Approved	Checked	Date	Rev	Reference
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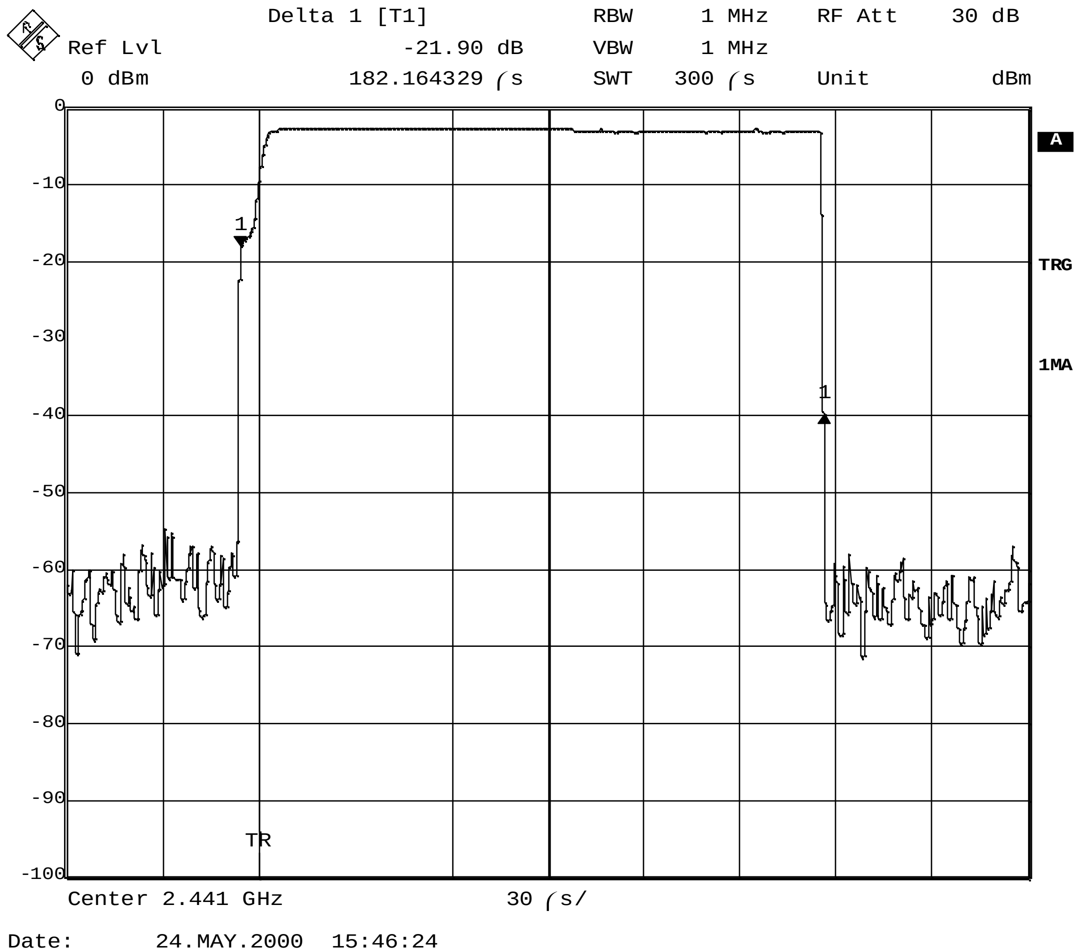

Figure 9: 300 microsecond plot of activity on one channel in inquiry mode

Power density plot

The plots are given on the following figures of the power density in page and inquiry mode:

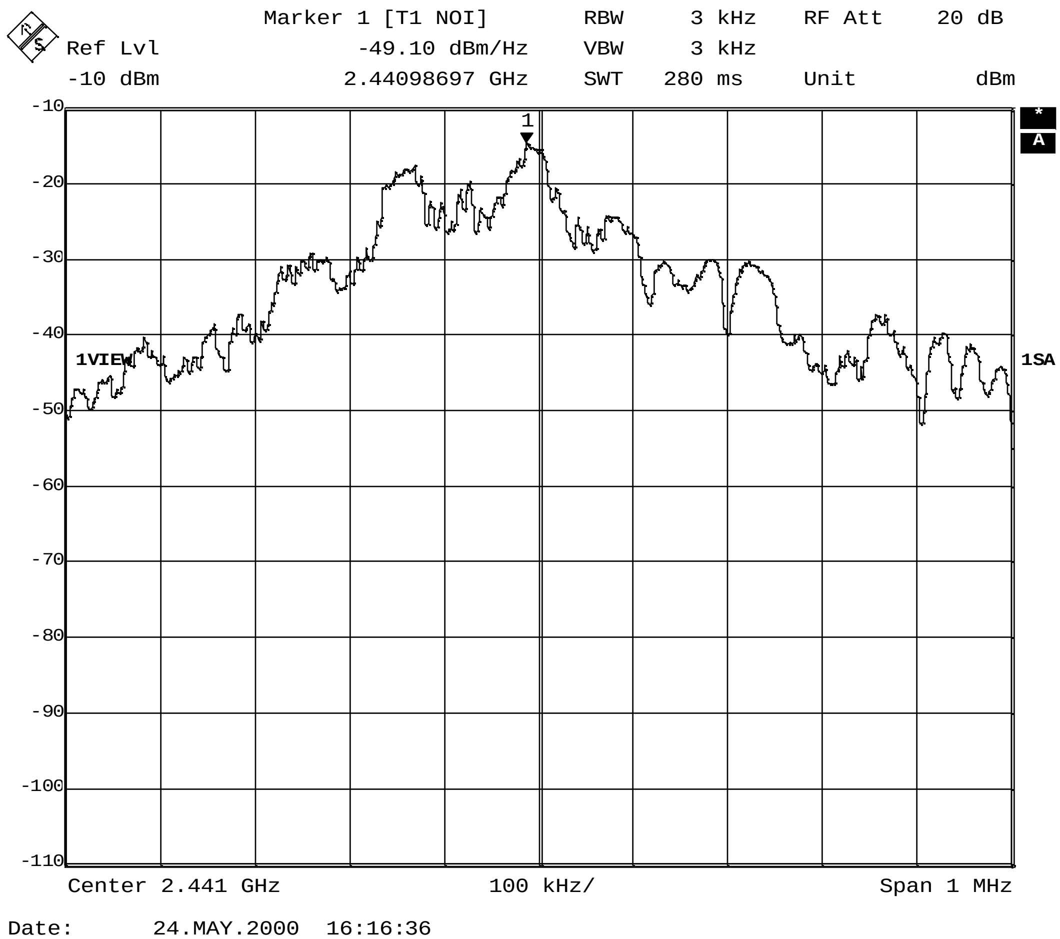

Figure 10: power density in page mode

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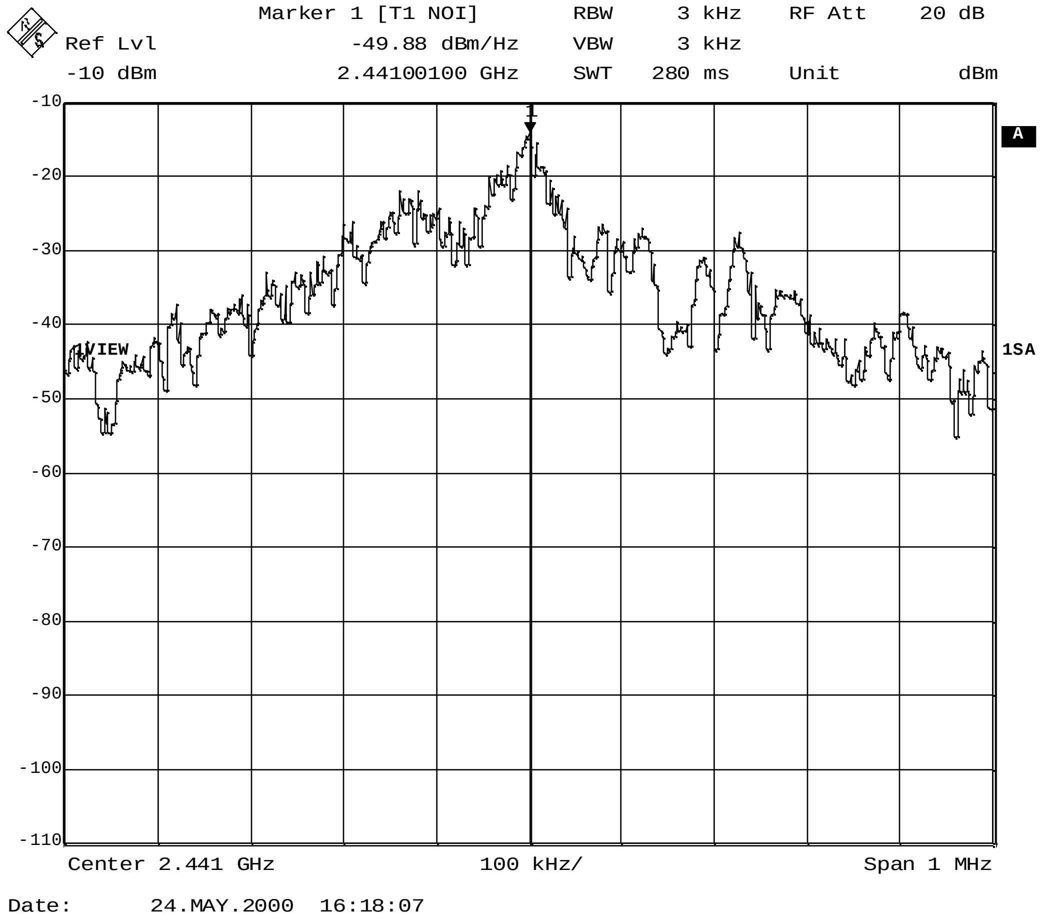

Figure 11: power density in inquiry mode

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Plots FCC 20 dB bandwidth in page and inquiry modes

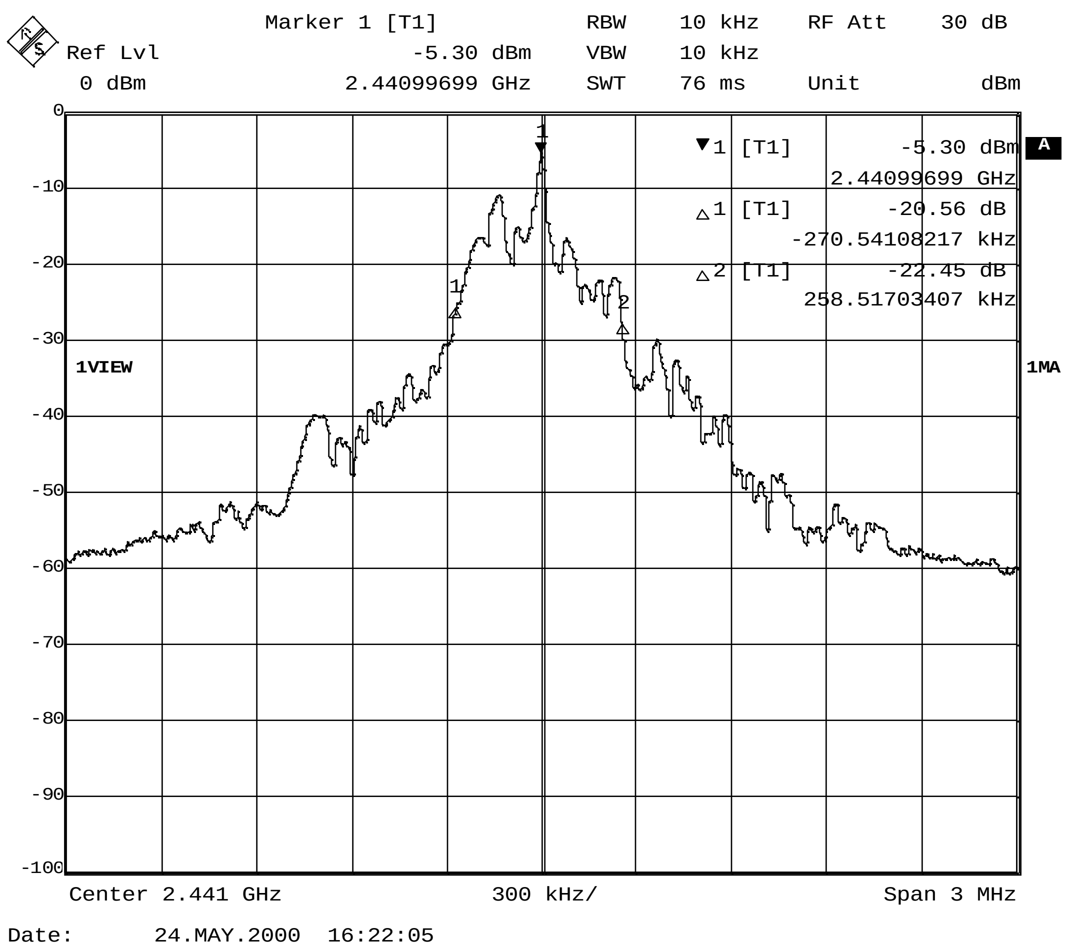

Figure 12: FCC 20 dB bandwidth in page mode

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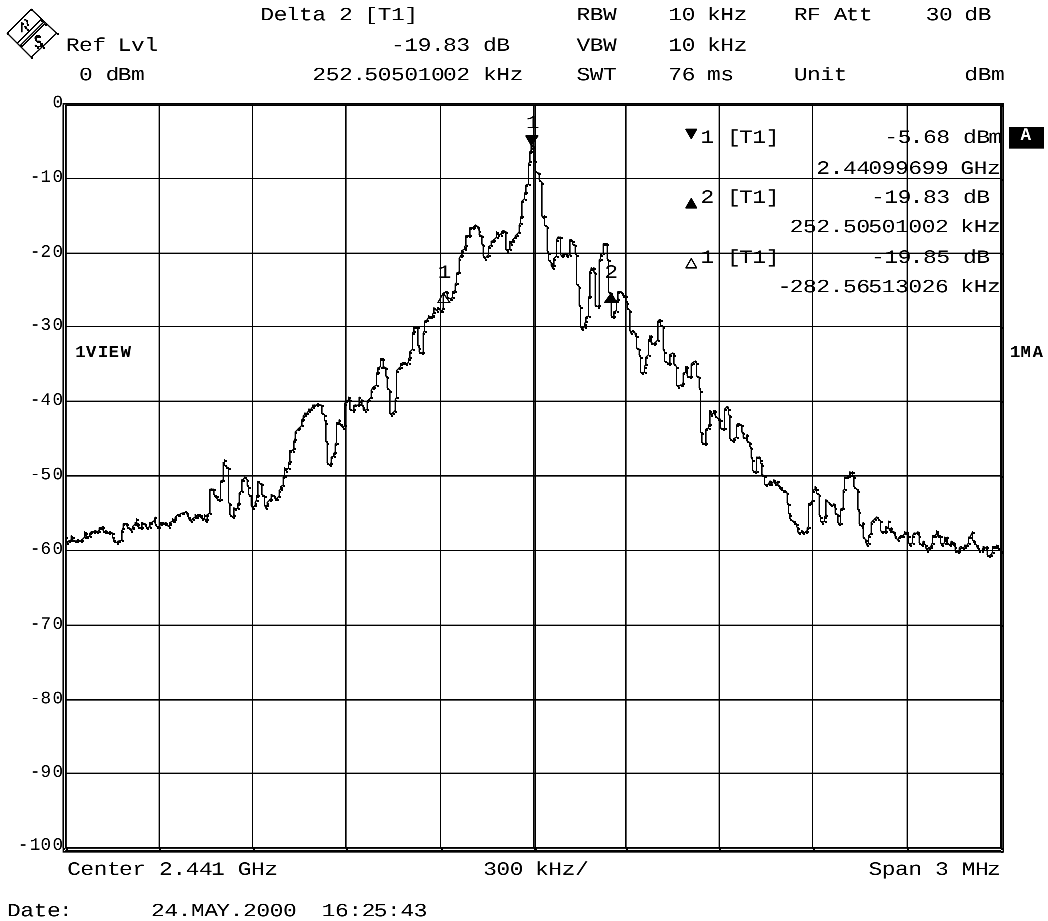

Figure 13: FCC 20 dB bandwidth in inquiry mode

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PROCESSING GAIN MEASUREMENT RESULTS OF ERICSSON'S BLUETOOTH RECEIVER USING THE CW-JAMMING MARGIN METHOD

Abstract

This paper presents results concerning the processing gain (PG) for Ericsson's Bluetooth receiver when measured according to FCC's CW-jamming margin method. The PG from the direct sequence spreading caused by the access code in page and inquiry mode is found to be about 4 dB for three different access codes, with considerably different properties. Therefore, since Bluetooth in page and inquiry is considered as a hybrid system which is required to have a total PG of 17 dB, and the PG from the frequency hopping part is 15 dB, it is concluded that Ericsson's receiver passes the test with a margin of about 2 dB.

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Contents

1 INTRODUCTION

FCC has expressed that they preferably would like the processing gain obtained from the DS part to be measured by a (possibly modified) CW jamming margin method. Ericsson has performed such a measurement, and in this paper it is described how this measurement is performed together with the result showing that the PG from the DS part is about 4 dB. Consequently, it is concluded that Ericsson's receiver has a PG from the DS part which exceeds the required 2 dB, and thus a total PG exceeding 17 dB, so that it indeed fulfils the by FCC imposed requirements.

The remaining part of the paper is organized as follows. In Section 2, the CW-jamming method is recapitulated, and all parameter values that have to be determined for an measurement are given. Measurement method and results are given in Section 3. Finally, in Section 4, conclusions are drawn.

2 DESCRIPTION OF THE METHOD

Referring to FCC §15.247 (e)(2), the processing gain may be determined as measured using the CW jamming margin method, which, for the sake of completeness, is repeated here:

A signal generator is stepped in 50 kHz increments across the passband of the system, recording at each point the generator level required to produce the recommended Bit Error Rate (BER). This level is the jammer level. The output power of the intentional radiator is measured at the same point. The jammer to signal ratio (J/S) is then calculated, discarding the worst 20 % of the J/S data points. The lowest remaining J/S ratio is used to calculate the processing gain, as follows:

$$G_p = S/N + M_j + L_{sys},$$

where G_p = the processing gain of the system, S/N = signal to noise ratio required for the chosen BER, M_j = J/S ratio, and L_{sys} = system losses. Note that total losses in a system, including intentional radiator and receiver, should be assumed to be no more than 2 dB.

In Bluetooth, the despreading is accomplished by correlating the received bit stream with the bit pattern of the access code. Then the value of this correlation determines whether or not the access code should be considered as present.

For Bluetooth, a "bit error" corresponds to that either the access code is present, but falsely rejected, or that the access code is absent but falsely accepted. The probability of the latter is negligible when compared to the former for any reasonable user scenario, and thus the false rejection ratio (FRR) is the figure of merit when evaluating the PG of the system. To reflect this, the CW jamming margin method, when applied to the Bluetooth system is interpreted as follows:

A signal generator is stepped in 50 kHz increments across the passband of the system, recording at each point the generator level required to produce the recommended false rejection ratio (FRR). This level is the jammer level. The output power of the intentional radiator is measured at the same point. The jammer to signal ratio (J/S) is then calculated, discarding the worst 20\% of the J/S data points. The lowest remaining J/S ratio is used to calculate the processing gain, as follows:

$$G_p = S/N + M_j + L_{sys},$$

where G_p = the processing gain of the system, S/N = signal to noise ratio required for the chosen FRR, M_j = J/S ratio, and L_{sys} = system losses. Note that total losses in a system, including intentional radiator and receiver, should be assumed to be no more than 2 dB.

It should here be noted that in order for the above test to be meaningful, the correct sampling time must have been found. If this is not the case, the BER would of course not be at an interesting level. For Bluetooth, the access code, whether in page, inquiry, or connection mode, is used to actually find the a suitable sampling point.

2.1 SYSTEM LOSSES

In the calculation of Gp, it is stated that one may include a term to account for the system losses. For Bluetooth, the two major causes for system loss are by Ericsson considered to be:

1. Non-optimal sampling time. As described above, the CW-jamming method assumes that the sampling time has been determined, whereas in Bluetooth, the sampling time is in fact found through the use of the access code.

2. The use of an IF bandpass filter which has a bandwidth less than 1 MHz. Due to the fairly strict requirements on the protection ratios for the adjacent channels, the IF filter is narrower than the channel spacing. Since the SNR is measured over a bandwidth of 1 MHz, this means that the SNR after the IF filter is, which cannot be measured actually is higher. Consequently the measured PG will be smaller.

Since FCC does not accept more than a 2 dB system loss, we expect that the above sources to losses together with the ever-present losses due to attenuation, should be sufficient to motivate for these 2 dB.

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2.2 OPERATING POINT

The access code is decided as present if the number of correctly decoded symbols in the 64 bit sync word exceeds a certain threshold, T. If the probability of bit error in the access code is denoted by p, and the errors are assumed to be independent, then the FRR can be calculated as

$$FRR = 1 - \sum_{t=0}^{64-T} \binom{64}{t} p^t (1-p)^{64-t}$$

We have chosen to determine the PG when the FRR equals 0.1%. The major reason for this being that a smaller number results in a too long testing time.

Furthermore, the SNR should preferably be somewhere between 15 and 25 dB. In the Bluetooth specification, 21 dB is the operating point where the raw BER in the payload is required not to exceed 0.1\%. Referring to the equation for the FRR, and choosing T = 61, p becomes 0.3 %. Consequently, for a receiver that is just passing the sensitivity requirement in the Bluetooth specification, this corresponds to an operating point of about 19-20 dB.

3 MEASUREMENT RESULTS

To measure the FRR, the output of the correlator in the Bluetooth baseband part is connected to a frequency counter. Valid access codes are then transmitted by an signal generator with a rate of 800 access-codes per second, since the normal frame repetition time is 1.25 ms. When the SNR is sufficiently high there will be 800 pulses per second at the output of the correlator.

When noise is present (or an interfering CW Jammer) there will be erroneously detected bits that will cause access codes to be rejected when the correlator threshold is not exceeded. In all measurements the threshold of the correlator is set to 61, and thus only 2 bits of the access code may be corrupted to still produce a correlator output pulse after receiving the access code. The required SNR at this threshold is approximately 18 dB. This is also in accordance with that predicted by theory and close to normal operating conditions of the system.

In part one of the measurement we will provide the receiver with a well defined SNR in order to obtain a FRR of 0.1%. This means for every 1000 transmitted access codes there will be one rejected and therefore will give no output pulse from the correlator.

To obtain sufficient accuracy in this measurement the measurement time should be long enough. We choose 60 seconds as the measurement time. With 800 access codes per second, we should have 800*60=48000 correlator pulses in 60 seconds. At a FRR of 0.1% there will be 48 pulses missing, giving 48000-48=47952 counted pulses in 60 seconds. This equals to 799.2 correlator pulses per second, which will be the reading on a frequency counter.

3.1 SIGNAL TO NOISE MEASUREMENT

In practice, the measurement of the S/N for 0.1% FRR is done by adding noise to the wanted signal. The Noiselevel relative to the wanted signal level is adjusted until the FRR is measured as 0.1%. Then the wanted signal power and the noise signal power are measured to obtain the S/N for 0.1% FRR.

3.2 JAMMER TO SIGNAL MEASUREMENT

For measurement of the JSR, the RF signal generator with the Bluetooth modulation is set to a fixed level 20 dB above the receiver sensitivity. The jammer is stepped in 50kHz steps across the receiving channel and for each step the jammer level is adjusted until the FRR is 0.1%. The ratio between the jammer power and the signal power is the Jammer to Signal ratio for 0.1% FRR.

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3.3 USED EQUIPMENT

The following table lists the equipment that was used during the measurements.

Item	Function	Type	Manufacturer	Ericsson internal number
1	Data generator	AMIQ	Rohde&Schwarz	0006188
2	RF signal generator	SMIQ	Rohde&Schwarz	0006189
3	RF signal generator	SMHU	Rohde&Schwarz	0000721
4	Frequency counter	PM6673	Philips	0000204
5	RF signal combiner	42100	Anaren	-
6	RF signal combiner	42100	Anaren	-
7	RF spectrum analyzer	HP8596E	Hewlett&Packard	0006206
8	DC power supply	SN16A	B&O	0006250
9	RF signal generator	SME03E	Rohde&Schwarz	0005850
10	Frequency mixer	ZFY-11	Mini-Circuits	-
11	Bandpass filer helical	5102.41	Neosid	-
12	RF amplfier	HP8347	Hewlett&Packard	0001141
13	RF adjustable attenuator	HP8496-A + HP8494-A	Hewlett&Packard	0001195
14	Adjustable bandpass filter	50140	K&L	0001105
15	Wideband noisesource	NC6109	Noisecom	0001280
16	Oscilloscope	PM3380A	Philips	0003340
17	Lydia Bluetooth testboard	-	Ericsson	-

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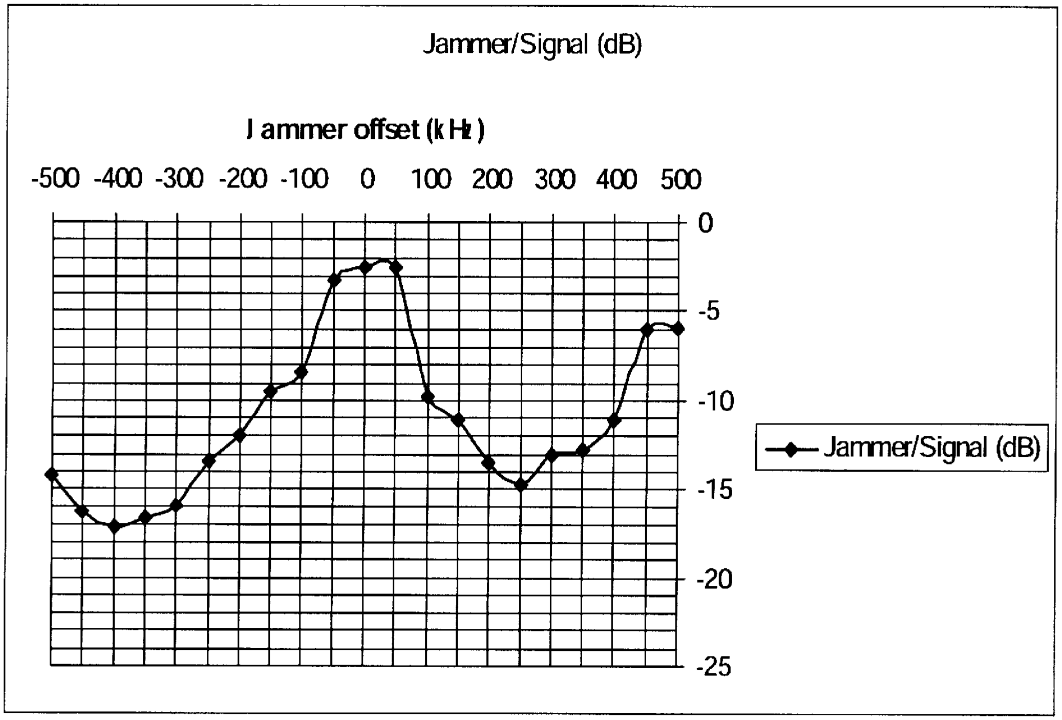
3.4 THE FIRST ACCESS CODE, LAP = 000000

For this access code, the required S/N was found to be 16.4 dB. The JSR required to get a FRR of 0.1 % as a function of the frequency offset for the jammer with respect to the carrier frequency is depicted in the figure below.

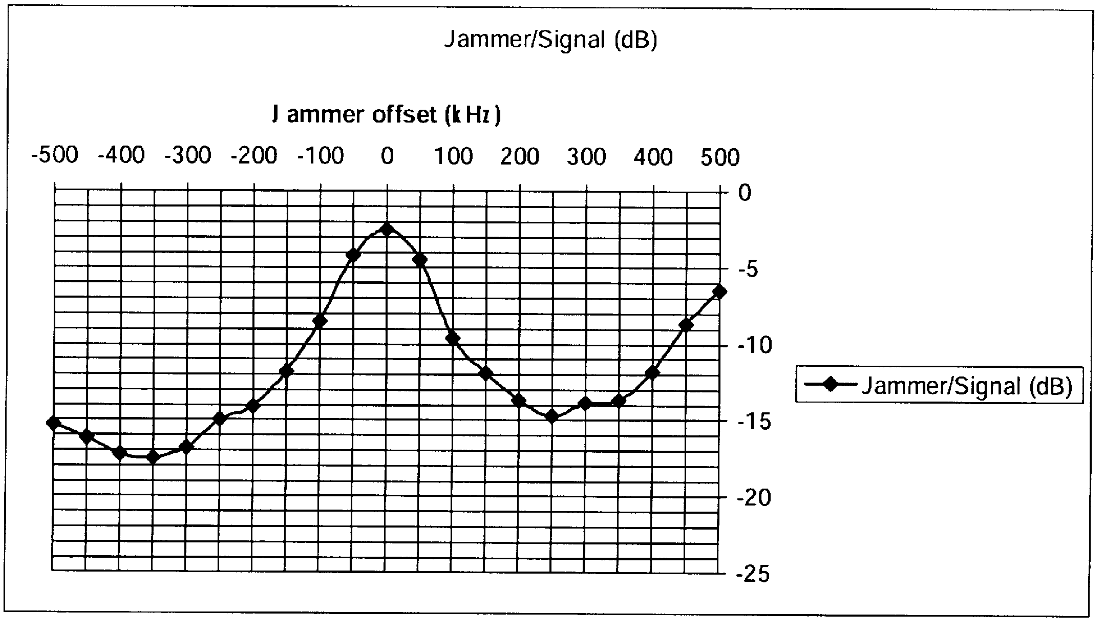


Disregarding the data points at -450 kHz, -400 kHz, -350 kHz, and -300 kHz, the worst data point is found to be at –14.7 dB (at +250 kHz). Thus, the PG becomes

$$G_p = 16.4 - 14.7 + 2.0 = 3.7 \text{ dB}.$$

3.5 THE SECOND ACCESS CODE, LAP = FFFFFF

For this access code, the required S/N was found to be 17.6 dB. The JSR required to get a FRR of 0.1 % as a function of the frequency offset for the jammer with respect to the carrier frequency is depicted in the figure below.

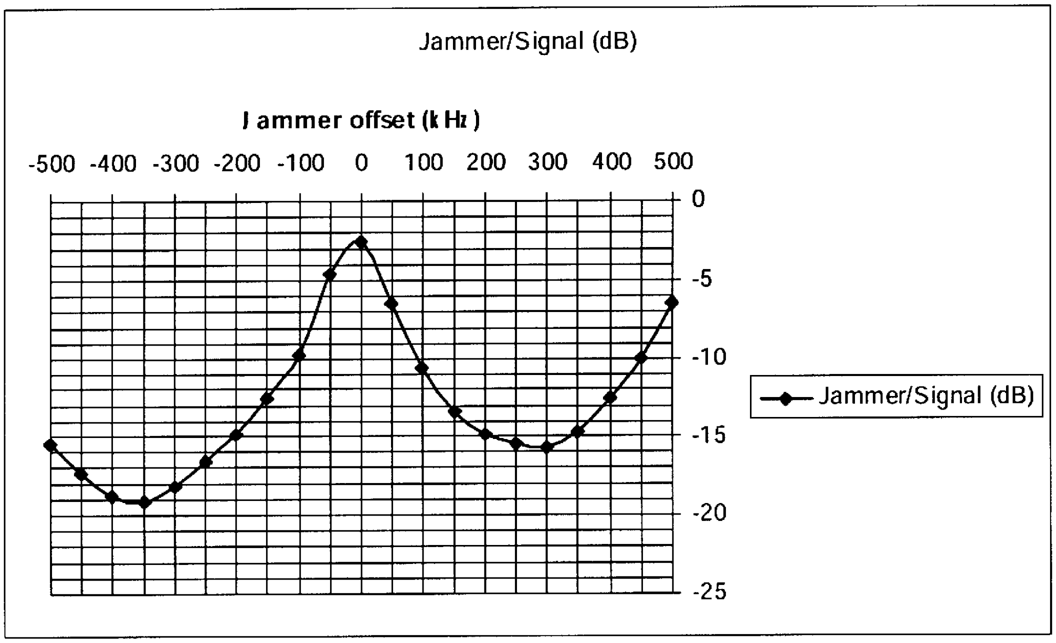


Disregarding the data points at –450 kHz, -400 kHz, -350 kHz, and -300 kHz, the worst data point is found to be at –15.3 dB (at –500 kHz). Thus, the PG becomes

$$G_p = 17.6 - 15.3 + 2.0 = 4.3 \text{ dB}.$$

3.6 THE THIRD ACCESS CODE, LAP = 65B333

For this access code, the required S/N was found to be 18.6 dB. The JSR required to get a FRR of 0.1 % as a function of the frequency offset for the jammer with respect to the carrier frequency is depicted in the figure below



Disregarding the data points at –450 kHz, -400 kHz, -350 kHz, and -300 kHz, the worst data point is found to be at –16.6 dB (at -250 kHz). Thus, the PG becomes

$$G_p = 18.6 - 16.6 + 2.0 = 4.0 \text{ dB.}$$

3.7 COMMENTS ABOUT THE MEASUREMENT RESULTS

Referring to the above measurement results, we see that the receiver performs better for the two first access codes, which can be explained by the intersymbol interference. Furthermore, we see that the receiver is somewhat asymmetric in that it performs better when the access codes has more zeros than ones. More importantly, though, the influence of access code affects both the noise performance and the jammer performance in a very similar way, so that the PG remains virtually unaffected.

4 CONCLUSIONS

FCC has expressed demands for that the PG obtained by the access code should be measured, and that they would like this to be done by the so-called CW-jamming margin method. In this report, Ericsson presents the results from such a measurement. The measurements were done for three different access codes with quite different properties at typical operating conditions for Bluetooth.The achieved PG is almost identical for these codes and fulfils the requirements for direct sequence processing gain for hybrid systems.