PROCESSING GAIN DOCUMENT

1. SCOPE

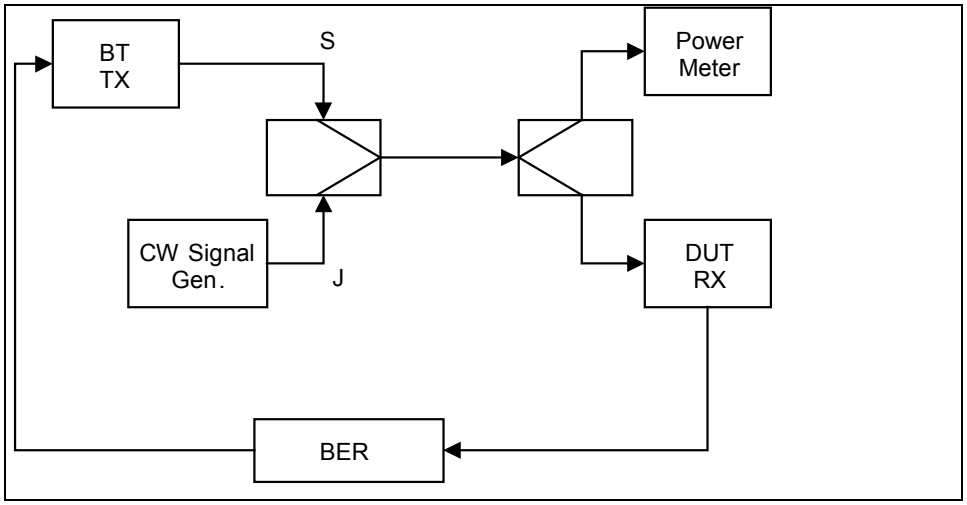
This document describes the requirements and measurement results for the processing gain requirement given for the US market by FCC, Part 15.247. This includes the description of the test setup.

2. HISTORY

The discussion about FCC's processing gain requirement started already long time ago between Nokia, Ericsson and FCC.

It was proposed by Ericsson (Jaap Haartsen) to regard the system as hybrid FH/DS during inquiry and paging. This approach was approved by FCC (see 7.).

FCC proposes the jamming margin test method to be used to demonstrate the processing gain of the DS component. FCC's proposed test setup:



The text in the FCC Part 15.247 section describes the measurement procedure as follows:

"As measured using the CW jamming margin method: 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: Gp = (S/N)o + Mj + Lsys, where Gp = processing gain of the system, (S/N)o = signal to noise ratio required for the chosen BER, Mj = J/S ratio, and Lsys = system losses. Note that total losses in a system, including intentional radiator and receiver, should be assumed to be no more than 2 dB.

(…)

Hybrid systems that employ a combination of both direct sequence and frequency hopping modulation techniques shall achieve a processing gain of at least 17 dB from the combined techniques."

3. REQUIREMENT

FCC (Part 15.247 document) requires for FH systems operating in the 2.4 GHz band to use at least 75 hopping channels.

During inquiry and paging procedure Bluetooth only uses 32 hopping channels.

In this state Bluetooth is regarded as a hybrid FH/DS. This approach is approved by FCC. For such systems FCC requires a minimum processing gain of 17 dB, resulting from FH in combination with DS.

As 32 channels are used during inquiry and paging the resulting processing gain from the FH operation is 15 dB:

$$PG_{FH} = \frac{B_s}{B_m} = \frac{32MHz}{1MHz} = 32 \approx 15dB$$

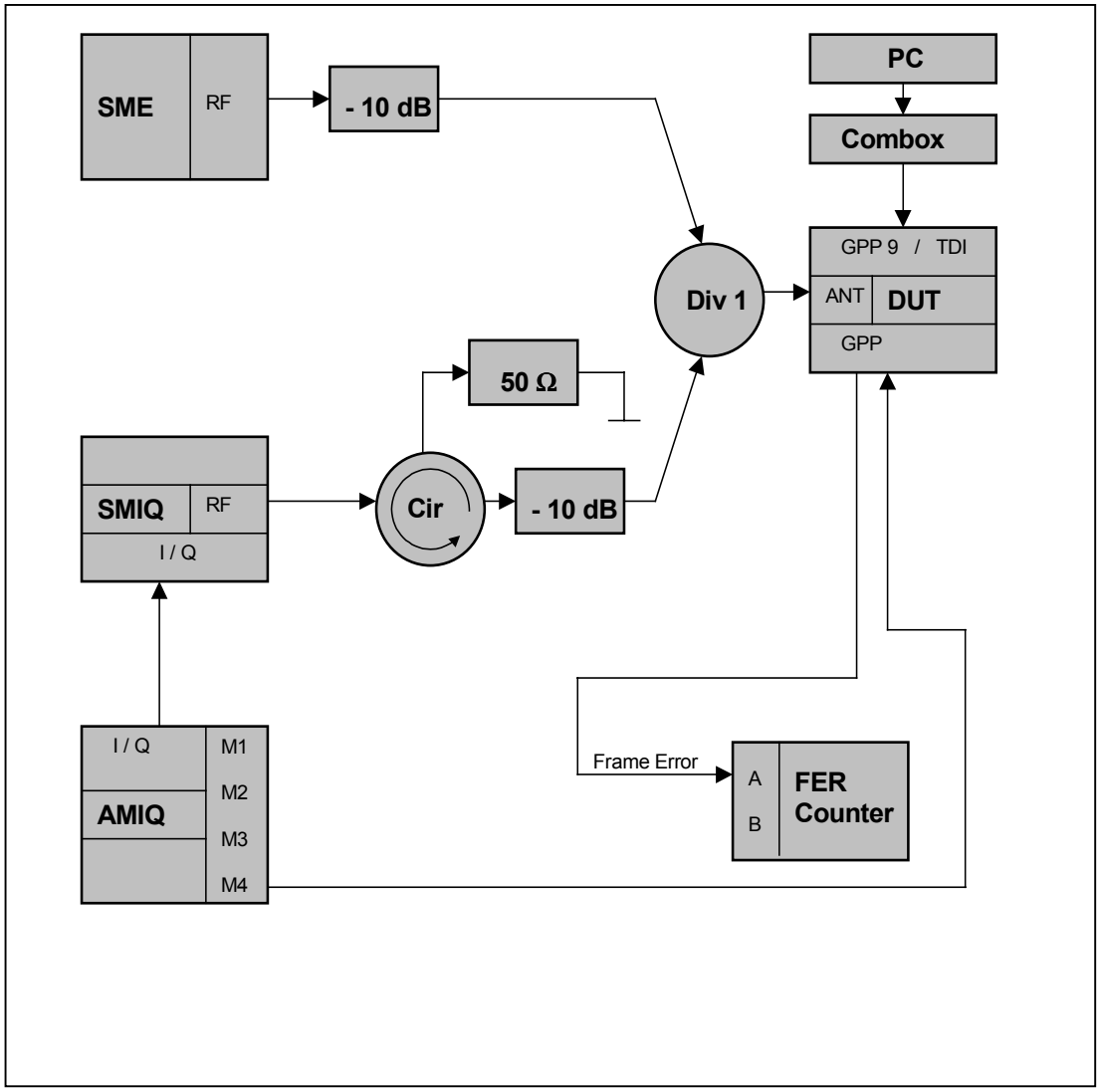
FCC accepts this.

The missing 2 dB should be gained by the DS operation of the access code during paging and inquiry. These 2 dB must be demonstrated by a 'real' measurement.

4. ABBREVIATION

Bluetooth	Bluetooth technology, created by an industry consortium, works in the 2,45GHz ISM band, with a gross data rate of about1Mbit/s, frequency hopping 1600 times a second over 79 channels being employed with a 1 MHz channel raster.
BT	Bluetooth
DS	Direct Sequence
FH	Frequence Hopping
FCC	Federal Communications Commission
DUT	Device under test

5. TEST SETUP



Shortcut	Equipment	Details
SME	Signal Generator	Rohde&Schwarz SME03, 5kHz-3GHz
SMIQ	Signal Generator	Rohde&Schwarz SMIQ03E, 300kHz-3,3GHz
AMIQ	IQ Modulation Generator	Rohde&Schwarz AMIQ
FER Counter	Universal Counter	Agilent 53131A
Combox	F-Bus connection to PC	Nokia Communication Interface

5.1 Test Procedure

The following test procedure is used to verify the processing gain of the DS component for the Bluetooth receiver:

a). Hopping off. BT TX (signal generator SMIQ) at f_c arbitrary chosen from the inquiry/paging hopping sequence.

b). CW jammer starts at f_c

c). BT TX (signal generator SMIQ) sends access codes (see 5.2) at signal level S. The timing of the TX signal is alligned to the scan window of the DUT RX.

d). Based on the correlator output (Sync found) of the DUT RX, frame errors are counted

e). Jammer level J iss increased until FER requirement is violated (≥ 1x10e-3)

The FER will be calculated based on 1x10e4 transmitted access codes.

f). This J / S level is recorded

g). Jammer signal frequency 50 kHz is increased/deacreased

h). c – g is repeated until the J/S values are comfortably compliant

i). The processing gain is calculated as described in the FCC procedure:

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:

$$PG = \left(\frac{S}{N}\right)_0 + \left(\frac{J}{S}\right)_j + L_{SYS},$$

j). a - i is repeated until all access codes (see 5.2) are tested

5.2 Tested Access Codes

It is clear that there are 'good' and 'bad' access codes from processing gain point of view.

FCC's processing gain requirement will be shown for the codes that are given in the following table:

Access Codes	LAP
GIAC	9E8B33
LIAC	9E8B00
'Worst case' codes	000000 FFFFFF 65B333

6. MEASUREMENT RESULTS

6.1 Device Under Test

Manufacturer	NOKIA GmbH
Testobject	Bluetooth component
DUT	LRB-1 and LRB-2
DUT Version	Baseband Chip Ollie2 and RF Chip Stan2
Testplatform	Knebel_Mother_02, BT101 Testboard

6.2 Pass Criteria

The processing gain PG, as measured, from the DS operation must be greater than 2 dB.

$$PG = \left(\frac{S}{N}\right)_0 + \left(\frac{J}{S}\right)_j + L_{SYS},$$

6.3 Testing Results

6.3.1 Signal to Noise Ratio $(S/N)_0$

$(S/N)_0$ is the required signal to noise ratio at the receiver input for a BER 1x10e-3.
The ideal equation/curve for GFSK is used to determine this value.

For the LRB-1 and LRB-2 Bluetooth components a signal to noise ratio of 16,4 dB is given.
The system loss L_{SYS} of maximal 2 dB is included.

6.3.2 Jammer to Signal Ratio $(J/S)_J$

$(J/S)_J$ is measured according to the test setup (see 5.).

The DUT is set in receive mode without hopping. The signal generator is set to transmit at f_c arbitrary chosen from the inquiry/paging hopping sequence. CW jammer starts at f_c, too. The signal generator sends access codes at signal level S. The timing of the TX signal is alligned to the scan window of the DUT RX. Based on the correlator output of the DUT RX,

frame errors are counted. Until FER requirement is violated (≥ 1x10e-3) the jammer level J is increased and the J/S ratio recorded.

frequency [kHz]	J/S [dB]				
	65B333	ZeroLap	Giac	AllOnes	9e8b00
-1000	12,5	13,9	12,2	15,8	12,3
-750	1	-0,3	-1	0,4	-1
-700	-3	-2	-2,7	-1,9	-3,2
-650	-6	-3,5	-4,4	-4	-5,1
-600	-7,4	-5,1	-7,1	-7,4	-7,3
-550	-8,3	-6	-7,6	-7,2	-9,3
-500	-10,6	-5,9	-9,1	-9,6	-9,5
-450	-10,6	-6,3	-8,9	-8,6	-9,5
-400	-9,4	-6,4	-9,8	-8,9	-10,3
-350	-9,3	-6,1	-9,3	-8,7	-9,1
-300	-8,5	-4,9	-8,4	-8,8	-8,2
-250	-7,6	-4,4	-8,1	-8,4	-7,7
-200	-6,6	-2,8	-7	-7,7	-6,8
-150	-5,7	-0,9	-6,3	-6,8	-6
-100	-5,5	-1,1	-4,9	-5,7	-5,2
-50	-4,2	-1	-2,4	-4,5	-3,7
0	-1,1	-0,8	-1,8	-2,2	-2
50	-1,2	-0,9	-3	-2	-2,6
100	-3	-4,1	-4,8	-1,6	-3
150	-5,9	-5,5	-5,7	-3,6	-5,2
200	-7,5	-6,4	-7,6	-6,5	-8,5
250	-8,8	-7,3	-9,2	-7,2	-9,6
300	-8,6	-7,9	-9,4	-7	-9,1
350	-9,9	-8,7	-8,9	-7,5	-9,7
400	-9,1	-7,4	-10,3	-8,9	-10,2
450	-10,8	-6,3	-10,2	-8,7	-10,5
500	-11,4	-5,9	-9,8	-9,9	-10,1
550	-9	-5	-8,9	-7,8	-8,8
600	-6,9	-3,2	-7,5	-6,3	-8,2
650	-4,8	-1,3	-5	-4,8	-6
700	-2	0,4	-2,3	-2,6	-2,1
750	1,6	2,1	0,3	-0,5	0,4
1000	15,4	18,3	14,9	15,1	15,3

Discarding the worst 20 % of the J/S data points, which is according to the requirements, the lowest remaining J/S ratio is used to calculate the processing gain as follows :

6.4 Calculation of Processing Gain

Access Code	J/S [dB]	S/N + L_{SYS} [dB]	$PG = \left(\frac{S}{N}\right)_0 + \left(\frac{J}{S}\right)_j + L_{SYS}$ [dB]
65B333	-9,3	16,4	6,1
ZeroLap	-7,3	16,4	9,1
GIAC	-9,2	16,4	7,2
AllOnes	-8,7	16,4	7,7
9e8b00	-9,5	16,4	6,9

Taking in account the worst measured processing gain for the DS operation, a total processing gain for the hybrid system can be calculated.

$$PG_{DS} = \left(\frac{S}{N}\right) + L_{SYS} + \left(\frac{L}{S}\right) = 16{,}4dB - 9{,}3dB = 6{,}1dB$$

$$PG_{FH} = \frac{B_s}{B_m} = \frac{32MHz}{1MHz} = 32 \approx 15dB$$

$$PG = PG_{FH} + PG_{DS} = 15dB + 6{,}1dB = 21{,}1dB$$

6.5 Conclusion

This document has considered the Bluetooth components LRB-1 and LRB-2 in view of the FCC part 15.247 ruling. As the system is regarded as a combined FH/DS system. The combination of direct-sequence spreading and hopping gives the system sufficient processing gain during paging and inquiry procedures.

For the connect state, still a conventional FH operation is applied, but in this operation all 79 hops are used.

APPENDIX

Letter from FCC, regarding the test method to demonstrate the processing gain.

FCC.pdf