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ALCQ and
Fading Margin Measurement in Nokia FlexiHopper and FlexiHopper Plus Microwave Radios

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1. SCOPE

This application note covers the principles of ALCQ and automatic fading margin measurement in Nokia FlexiHopper and FlexiHopper Plus Radios. For information regarding commissioning, refer to FlexiHopper user manuals.

1.1 Definitions and Terminology

ALCQ	Automatic Level Control with Quality Measure
ATPC	Automatic Transmit Power Control
BER	Bit error Ratio or Rate here for pseudo errors before FEC correction in the outdoor units
D	Degradation of the BER 10-3 threshold
FEC	Forward Error Correction
HSB	Hot StandBy
M	Fading Margin
OU	Outdoor Unit
P	Power in dBm
PER	Parity Error Rate (IU)
RF	Radio Frequency
RX	Receiver related
SNR	Signal-to-Noise Ratio
TX	Transmitter related

2. INTRODUCTION

The main purpose of this document is to clarify the use of Automatic Level Control with Quality measure (ALCQ) in FlexiHopper and FlexiHopper Plus microwave radios[1]. The other purpose is to describe the functionality of the automatic fading margin measurement and how the results can be used in the calculation of ALCQ set points.

The main idea in ALCQ is to monitor the received signal level together with the bit error ratio (BER) of the receiver, and adjust the far-end transmitter output power to adapt to the fading conditions. In addition to these, FlexiHopper Radios apply also a novel pseudo error monitoring for controlling ALCQ. According to this Nokia invention, the bit errors detected by the forward error correction (FEC) decoder are interpreted as pseudo errors, and further, these errors are used as an additional input for ALCQ operation. In other words, this method can respond to degrading signal quality before actual bit errors begin to occur over the radio relay. This is considered a very attractive improvement compared to the traditional automatic transmit power control (ATPC) operations.

The ALCQ function comprises of the measurement of the received signal with different quality measures and sending the control commands back to the far-end transmitter. The main advantage of this feature is to achieve more efficient utilization of the radio frequencies compared to a constant Tx level approach or the ATPC approach. The controlled use of transmitted power reduces interference between systems, which allows tighter packaging of radio links within the same geographical area or at network star points. Alternatively, cheaper system components, e.g., smaller antennas could be used.

The following list summarizes the advantages of ALCQ over ATPC:

- more efficient utilization of radio frequencies,
- adaptation to the changing interference situations, and
- responding to the signal quality degradation before bit errors in 2M interface occur.

Today's tendency in radio link network planning is to have high efficiency in spectrum utilization. This means a great demand for the reuse of frequencies in nearby areas. At network branching points and stars, the designer is sometimes forced to use the same frequencies in hops having a small difference in their directions. Small angles could be used if interference between systems can be limited as much as possible.

At microwave frequencies, the main reason for signal attenuation is rain. One should avoid transmitting with unnecessary high power during good weather conditions, but at the same time, use enough power to maintain good residual BER performance.

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[1] The ETSI variant is called ATPC (Automatic Transmit Power Control) where the transmit power is based solely on the received level on the other end.

During rainy periods, higher power level should be transmitted to achieve maximum performance for the hop. This requires adaptability of the radio link system.

The real fading margin over the radio relay can be measured automatically with the FlexiHopper radio during the commissioning. This is an excellent tool for verifying the quality of the link installation and network planning. The measured fading margin value could be also applied when defining the optimum Tx power and ALCQ set point for the received power level as described in chapter 7.

3. PROPAGATION PHENOMENA AT FREQUENCIES 7... 38 GHZ

The dominating fading mechanisms depend on the radio link frequency. At lower frequencies up to about 7 GHz, the fading is due to multipath propagation. At low frequencies the hop lengths can be easily several tens of kilometers but the rain attenuation is still negligible. From 7 up to 15 GHz, both multipath propagation and rain attenuation has to be taken into consideration, whereas, from 15 GHz up to 38 GHz the rain attenuation is dominating over other fading mechanisms.

The fading caused by rain is flat over frequency. Multipath propagation can cause notches in the frequency response (dispersion) but is usually nearly flat in low to medium capacity radio link applications and at frequencies over 10 GHz.

Figure 1, Figure 2 and Figure 3 show how the hop length is related to the system value (here the antenna gains are included to the system value) of the hop. The typical rain amount depends on the geographical area, e.g., in Asia the rain rates are much higher than in Europe. However, a typical diameter of the most heavy rain spot in Asia is only 2 km, which is much less than the normal hop length at frequencies below 38 GHz.

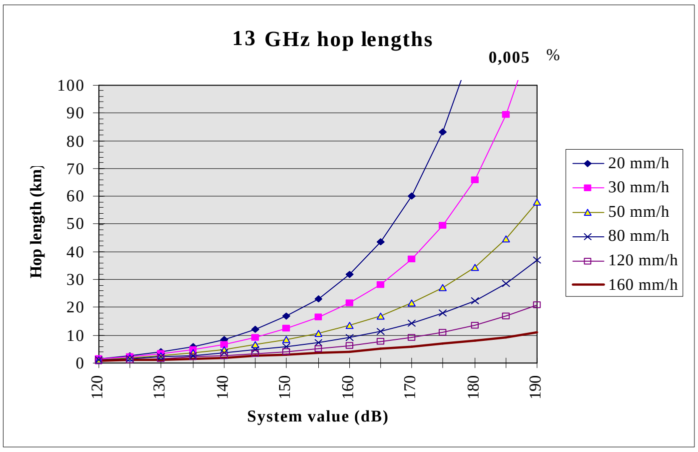

Figure 1: Rain limited hop lengths of 13 GHz radio links, unavailability 0.005 %.

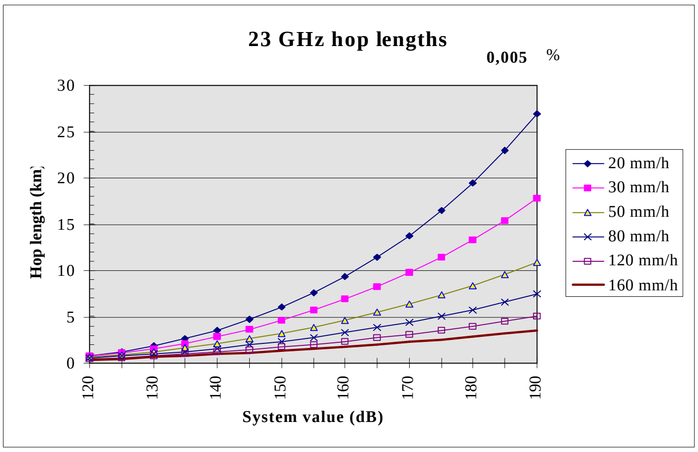

Figure 2: Rain limited hop lengths of 23 GHz radio links, unavailability 0.005 %.

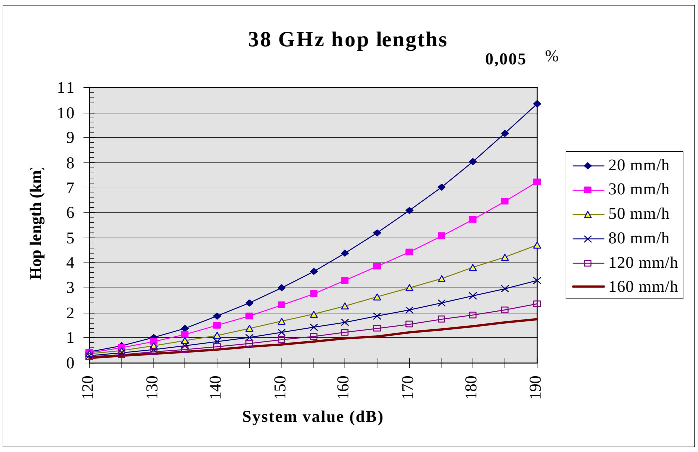

Figure 3: Rain limited hop lengths of 38 GHz radio links, unavailability 0.005 %.

4. BASICS OF ALCQ OPERATION

ALCQ operation is based on the measurements of the received signal level and quality as well as the adjustment of the far-end transmitter output power level. The purpose of ALCQ is to compensate for slow and fast signal level changes appearing in the radio path.

4.1 Measurements

In ALCQ mode, the radio receiver always monitors

a) Rx input level [dBm],

b) Rx level gradient [dB/s],

c) pseudo errors (BER), and

d) parity errors (PER).

Revolutionary *pseudo error* monitoring is based on the FEC decoder: It can indicate how many bits have been corrected in the outdoor unit. That is, in FlexiHopper radios bit errors appearing at the decoder input are interpreted as pseudo errors, since they will be corrected in the decoder (assuming that the maximum performance of the decoder is not exceeded). *Bit error ratio* (BER) for FlexiHopper ALCQ functionality is evaluated as the number of pseudo errors divided by the number of received bits. The gating time for the BER measurement is one second.

Parity error ratio (PER) for ALCQ functionality is measured in the indoor unit by counting frame parity errors. The gating time for the PER measurement is also one second.

4.2 Generation of ALCQ commands

Tx power control commands that can be generated by the radio receiver are

a) **increase quickly**,

b) **increase**, and

c) **decrease**.

The **increase quickly** command is generated when

a) the parity error ratio exceeds the *PER limit*, or

b) the Rx input level fades faster than defined by the *Rx level gradient limit*, or

c) the Rx input level has fallen more than 12.5 dB below the Rx input level defined by the ALCQ set point.

With the **increase quickly** command, the Tx power of the far-end radio is forced to it’s maximum. The Tx power is kept there as long as defined by the *PER delay time* setting or by the *fading delay time* setting.

The **increase** command is generated when

a) the pseudo error ratio exceeds the *BER limit* or

b) the Rx input level has faded 2.5 dB below the Rx input level defined by the ALCQ set point.

With the **increase** command, the Tx power of the far-end radio is increased by 2 dB. There is always a 5 second delay between two consecutive **increase** commands.

The **decrease** command is generated when

a) the pseudo error ratio is below the *BER limit, or*

b) the parity error ratio is below the *PER limit*, or

c) the Rx input level is 2.5 dB above the Rx input level defined by the ALCQ set point.

With the **decrease** command, the Tx power of the far-end radio is decreased by 1 dB. There is always a 5 second delay between two consecutive **decrease** commands.

4.3 ALCQ Parameters

Table 1 desribes all the essential ALCQ parameters.

Table 1: ALCQ parameters.

Parameter	Description
ALCQ status	• From the user with Hopper Manager • on/off
ALCQ set point	• From the user with Hopper Manager • Value in dB's above the interference-free 10^{-3} threshold level
Parity error ratio limit	10^{-3}
PER delay time	5 seconds
Pseudo error ratio limit	$100 \cdot 10^{-9}$
BER delay time	5 seconds
Rx input level gradient limit	10 dB/s
Fading delay time	10 seconds

4.4 Examples of Power Control

Figure 4 shows the behavior of the received power level for some transmission conditions. At point **A,** the received power level reaches the minimum limit (ALCQ set point - 2.5 dB) and one **increase** command is sent. At point **B,** the Rx power level reaches the maximum allowed level and one **decrease** command is sent. At point **C,** the Rx power fades too rapidly and an **increase quickly** command is sent. After the fading delay time **T1** at point **D**, **decrease** commands are sent until the received power level reaches the ALCQ set point value. At point **F**, an increased PER is detected and an **increase quickly** command is sent. After error delay time **T2** (i.e. PER delay time), **decrease** commands are given until the ALCQ set point range is reached again.

This figure does not show ALCQ operation when pseudo errors have been detected by the FEC decoder. However, the operation is similar to points A and B, i.e., the pseudo error detection results only in an **increase** Tx power command sending and the subsequent **increase** or **decrease** commands after the BER delay time.

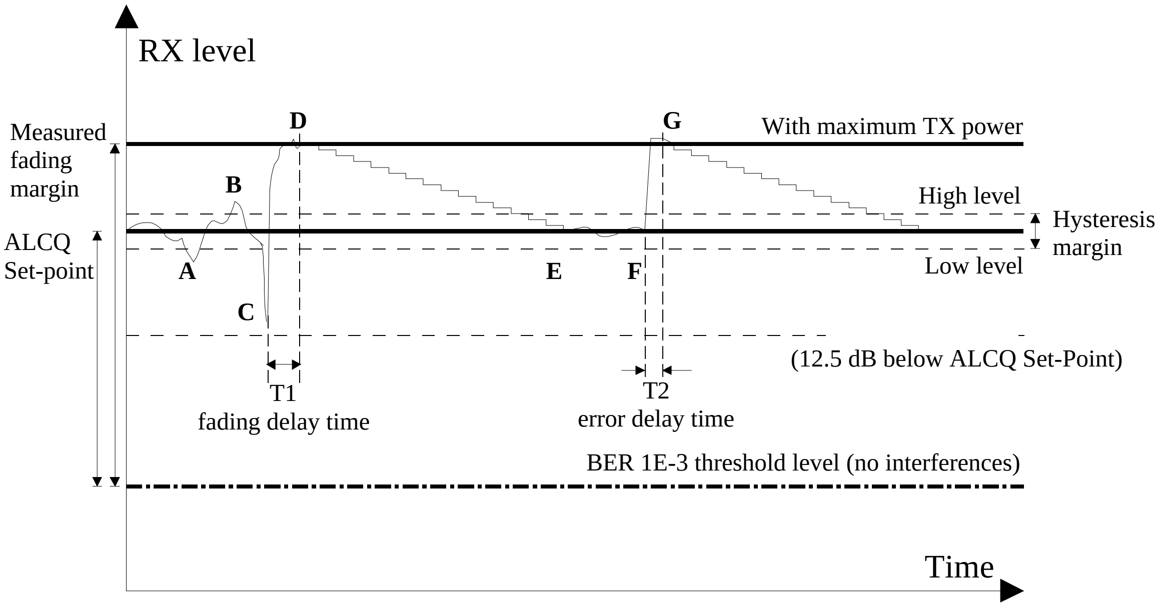

Figure 4: Example of ALCQ operation during different radio channel conditions.

5. ALCQ IN PROTECTED MODES

5.1 HSB and HSB + Space Diversity

This example (see Figure 5) shows how the indoor unit controls two protected outdoor units when ALCQ has been enabled. Although both outdoor units 2A and 2B receive the signal, the indoor unit has selected the outdoor unit 2A to be the primary receiver. However in this example, the outdoor unit 2B transmits the signal but the outdoor unit 2A does not.

Only the outdoor unit, which is selected by the indoor unit for signal reception (2A), will make ALCQ control commands for the far-end. In contrast to the data path, the ALCQ status is not checked on a frame-by-frame basis but checked only every second. If the mute is on in this outdoor unit (2A), the ALCQ command is first sent to the transmitting outdoor unit in the near-end (2B), which will, consequently, forward the message to the far-end. At the far-end, both outdoor units will receive the command but only the transmitting one will execute it.

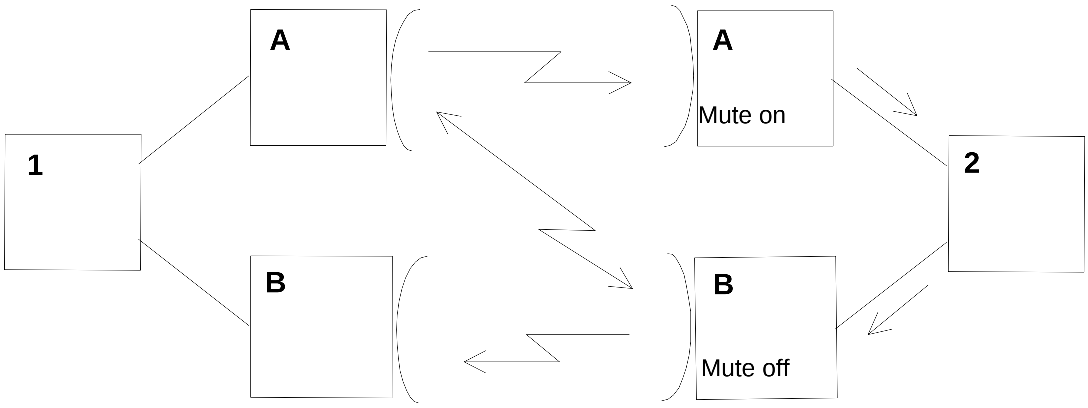

Figure 5: ALCQ in HSB+space diversity mode.

5.2 Frequency Diversity

In this example (see Figure 6) both outdoor units send and receive signals at their own Tx frequencies. ALCQ operates in the same way as in the single mode.

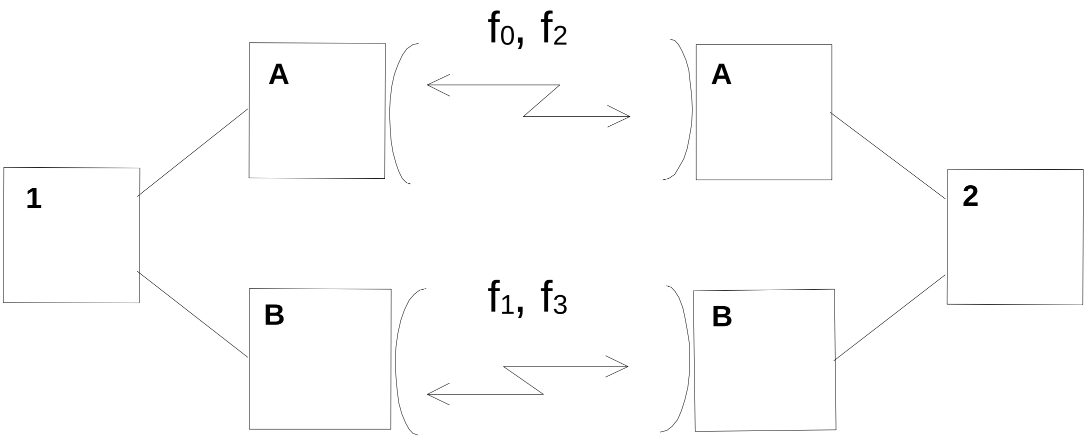

Figure 6: ALCQ in frequency diversity mode.

6. FADING MARGIN MEASUREMENT

6.1 Principles

During the commissioning of the FlexiHopper radio relay, the user can execute the fading margin measurement with Hopper Manager. The fading margin measurement takes about 1 minute. The measured fading margin can be used to verify the quality of the radio link network planning. In addition, it can be used for defining a sensible ALCQ Rx level set point. The measurement is carried out without the aid of any additional tools or measurement equipment. The fading margin measurement of a commissioned radio relay is based on two measurements:

1) the received interference signal level and
2) the normal (maximum) received power level.

With these measurements it is straightforward to calculate the fading margin. Before the measurement procedure can be described, the reader must be familiar with the following definitions:

Generally, the *fading margin* is defined here as a difference between the normal received signal level and the required signal level for 10^{-3} BER in the actual operation conditions over the commissioned radio hop.

The *normal received signal level* is measured when the far-end radio is transmitting with the maximum allowed transmit power in normal conditions. The maximum allowed transmit power is set by the user during commissioning. This value, however, cannot exceed the maximum transmitter power specified for the outdoor unit. The maximum transmitter power depends on the frequency band of outdoor unit.

The *BER 10^{-3} threshold level* is a received signal level at which the bit error rate of 10^{-3} over the hop is reached. In the field co- and adjacent channel interference from other microwave radios cause this level to increase from the interference-free value measured by Nokia factory under ideal conditions. This degraded level needs not to be measured in the field but is calculated indirectly by FlexiHopper automatic fading margin measurement procedure to determine the fading margin.

6.2 Procedural Steps of Fading Margin Measurement

1. When the FlexiHopper radio is manufactured, following two measurements are made: the 10^{-3} threshold level and the receiver's noise floor level. The results of these precise measurements are stored into the radio. The threshold level is described as $P_{rx,1e-3}$ and the noise floor level is described as $P_{rx,noise}$. Thus, the minimum (threshold) signal-to-noise ratio of the radio is

   SNR_{min} [dB] = $P_{rx,1e-3}$ [dBm] - $P_{rx,noise}$ [dBm].

2. When the radio link equipment has been installed, the fading margin measurement can be started using Hopper Manager software. The measurement procedure is the following: First, the outdoor units stop transmitting for about 15 seconds. Both outdoor units measure the Rx power levels at their antenna ports. The meas-

ured Rx power level is described here as $P_{rx,noise+interference}$. This Rx power consists of the noise generated in the receiver and the signals generated by surrounding interference sources.

3. When the $P_{rx,noise+interference}$ levels have been measured, both outdoor units start transmitting at the maximum (user-defined) transmit power. The both outdoor units are able to measure then the maximum received signal level P_{rx}.

4. The fading margin, M, is finally calculated from P_{rx}, $P_{rx,noise+interference}$, and SNR_{min} values. The fading margin is well approximated by

$$M \text{ [dB]} = P_{rx} \text{ [dBm]} - (SNR_{min} \text{ [dB]} + P_{rx,noise+interference} \text{ [dBm]}),$$

where the term (SNR_{min} + $P_{rx,noise+interference}$) is the estimated 10^{-3} threshold level, $P_{rx,1e\text{-}3\ interference}$, including interference signals at the antenna port.

The measured fading margin value is only valid with the commissioning settings (mode, capacity, maximum allowed Tx power, and TX frequency). After changing any commissioning settings, the fading margin has to be measured again. The fading margin measurement can be carried out also in different equipment and propagation protection modes.

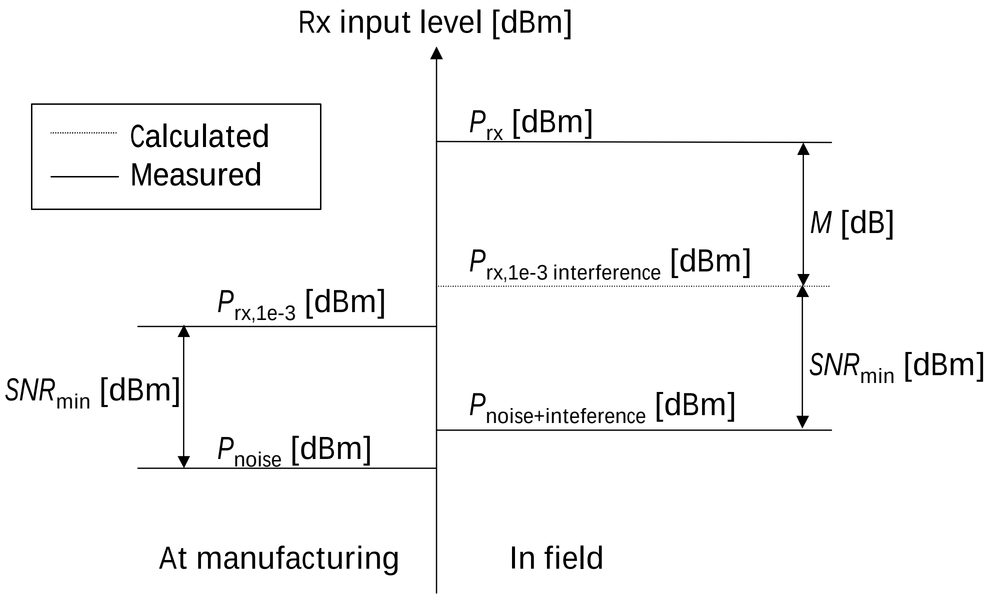

Figure 7: Fading Margin Measurement.

7. ALCQ SET POINT CALCULATION

ALCQ allows the transmit power to vary within the chosen maximum[2] TX power and the given minimum[3] TX power. This range is called the ATPC range. The difference between maximum and minimum TX power will be denoted in the following as *ATPC*.

The trade-off between causing interference to neighboring hops and being vulnerable to fading has resulted during network planning to a desired fading margin, $M_{desired}$, at desired TX power for normal transmit conditions and a desired maximum TX power for bad transmit conditions.

When calculating the ALCQ set point for a given measured fading margin, two main situations can now be distinguished which depend on the desired minimum TX power and the desired fading margin.

7.1 ALCQ Set Point for Minimum TX Power Under Normal Conditions

When ALCQ is activated, network planning usually assumes that under good transmission conditions the lowest TX power of the ATPC range, i.e. minimum TX power, is used. The minimum TX power can only be reached if the ATPC range, *ATPC,* is smaller than the measured fading margin, *M*. The difference between the measured fading margin, *M*, and the ATPC range gives the fading margin at the minimum TX power, M_{ATPC}:

$$M_{ATPC}\,[\text{dB}] = M\,[\text{dB}] - ATPC\,[\text{dB}].$$

In other words, in order to be able to find a corresponding ALCQ set point, where the TX power is at the minimum level under good transmission conditions, the sum of the desired fading margin, $M_{desired}$, and the ATPC range, *ATPC*, has to be smaller than the fading margin, *M* (see Figure 8).

Because the reference Rx level for the ALCQ set point is the BER 10^{-3} threshold level without interference, $P_{rx,1e\text{-}3}$, the measured fading margin, *M*, reduced by the ATPC range, *ATPC*, has to be increased by the threshold degradation, *D*, in order to get the ALCQ set point i.e.

$$ALCQ\ set\ point\,[\text{dB}] = M_{ATPC}\,[\text{dB}] + D\,[\text{dB}],$$

$$= M\,[\text{dB}] - ATPC\,[\text{dB}] + D\,[\text{dB}],$$

where

$$M\,[\text{dB}] = P_{rx}\,[\text{dBm}] - P_{rx,1e\text{-}3,interference}\,[\text{dBm}]$$

and

$$D\,[\text{dB}] = P_{rx,1e\text{-}3,interference}\,[\text{dBm}] - P_{rx,1e\text{-}3}\,[\text{dBm}].$$

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[2] The absolute maximum TX power depends on the frequency band.

[3] The minimum TX power depends on the capacity and the frequency band.

On the other hand, calculating the ALCQ set point using the knowledge of the Rx input level at maximum TX power, P_{rx}, the 10^{-3} Rx input level during manufacture, $P_{rx,1e-3}$, and the ATPC range, *ATPC*, gives:

$$ALCQ\ set\ point\ [dB] = P_{rx}\ [dBm] - P_{rx,1e-3}\ [dBm] - ATPC\ [dB].$$

P_{rx} can be easily measured and $P_{rx,1e-3}$ is available in the factory report of the identifications.

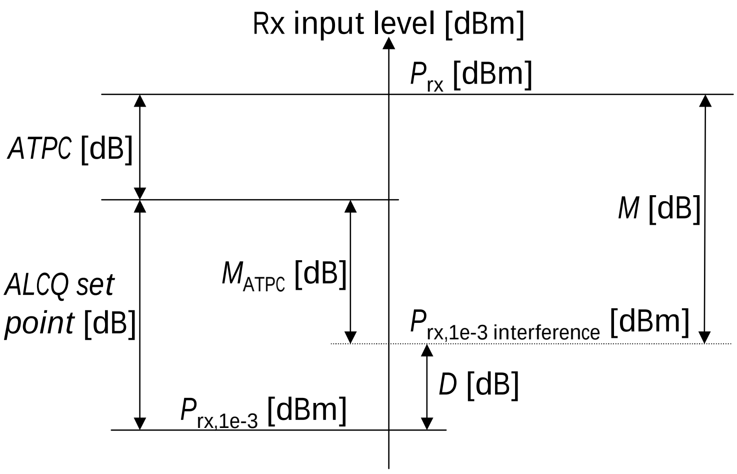

Figure 8: Defining ALCQ set point under normal condition.

7.2 ALCQ set point for given fading margin

In a case where the sum of ATPC range, *ATPC*, and the desired fading margin, $M_{desired}$, is larger than the measured fading margin, *M*, and the measured fading margin is still larger than the desired fading margin, the usable ATPC range must be limited by choosing a corresponding ALCQ set point which prohibits to go down to the minimum TX power. This reduced ATPC range will be called $ATPC_{reduced}$ in the following (see Figure 9):

$$ATPC_{reduced}\ [dB] = M\ [dB] - M_{desired}\ [dB].$$

The ALCQ set point then is calculated similarly to the previous sub-chapter as

$$ALCQ\ set\ point\ [dB] = M_{desired}\ [dB] + D\ [dB],$$

$$= M\ [dB] – ATPC_{reduced}\ [dB] + D\ [dB]$$

with

$$D\ [dB] = P_{rx,1e-3,interference}\ [dBm] - P_{rx,1e-3}\ [dBm].$$

This gives

$$ALCQ\ set\ point\ [dB] = P_{rx}\ [dBm] - P_{rx,1e\text{-}3}\ [dBm] - ATPC_{reduced}\ [dB]$$

$$= P_{rx}\ [dBm] - P_{rx,1e\text{-}3}\ [dBm] - M\ [dB] + M_{desired}\ [dB].$$

If, as assumed at the beginning of this sub-chapter, the *ATPC* range is greater than $ATPC_{reduced}$, the transmit power used under normal conditions is then increased from the minimum value by the difference of *ATPC* and $ATPC_{reduced}$. Otherwise the minimum TX power of the ATPC range causes that the fading margin will actually be greater than the desired fading margin and we are dealing with the case of the previous sub-chapter.

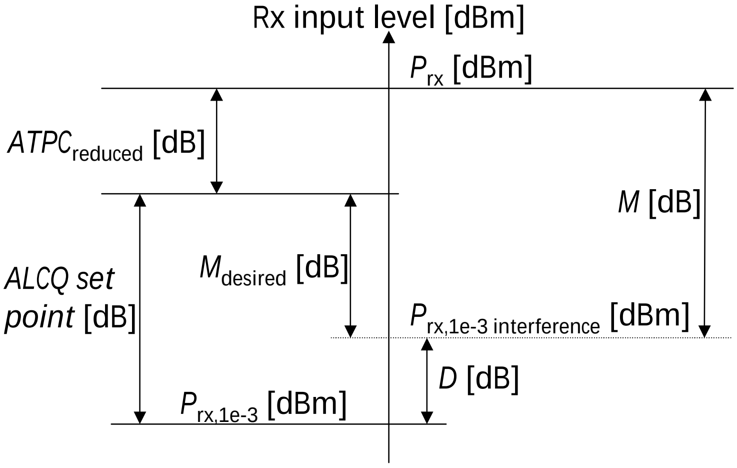

Figure 9: Defining ALCQ set point for given fading margin.

7.3 ALCQ set point calculation for HSB with asymmetric setups

When using ALCQ in HSB mode with asymmetric setups where one radio is receiving less power than the other, this has to be taken into account when calculating the ALCQ set point. One example of such a system is the one-antenna HSB configuration with unbalanced directional couplers. These couplers give more attenuation for the protecting radios than for the primary radios. The attenuation difference between the primary radio and the secondary radio due to the unbalanced coupler is 4 to 5 dB depending on the frequency band.

The coupler loss has to be taken into account in the calculation of ALCQ set points of the primary and secondary radios. This is done in the way that the ALCQ set point of the secondary radio is 4 to 5 dB lower than the ALCQ set point of the primary radio. If the ALCQ set points are set to the same level, the transmitter power is increased by 5 dB when the secondary radio is controlling the far-end transmitter. This may degrade the interference situation in the neigbouring radio systems.

When the primary and secondary radios in the HSB configuration are set to the same maximum transmit power, the automatic fading margin measurements will return 4 values out of which the diagonal values are approximately 5 dB less than the primary path and the values for the secondary path about 10 dB less.

For the calculation of the set point for the primary radios, the fading margin values of the direct path between the primary radios should be used. The calculation follows the methods of the previous chapters. The set point calculation of the secondary radios will be calculated starting with the margins from the diagonal path of the secondary radio to the primary radio. This results in subtracting approximately 5 dB from the set points of the primary radios.