# Title: On the Algebraic Channel Interleaver Design

## Source: Nortel Networks[1]

## 0.0 Summary

In this memo, we present a solution for Inter-Frame (1st) Interleaver and Intra-Frame (2nd) Interleaver design for 3GPP. The first interleaver is optimised and the second interleaver is a simple shuffling of bits from different Transport Channels.

The main advantages of the proposed solution are the following.

- very low complexity for both interleaving and de-interleaving (refer to Section 2.1 and 3.1)
- flexibility to cope with multiple frame sizes (refer to Section 2.1 and 3.2)
- robustness against fading (refer to Section 3.4)
- robustness to puncturing (refer to Section 3.3)
- smooth integration in 3GPP chain with other items considered today like grouped DTX or multiframe multiplexing (refer to Section 3.5)
- future proofness due to the flexibility towards frame sizes and the use of a formula as interleaving rule instead of tables storage (refer to Section 2.1 and 3.6)

With respect to the listed advantages, we recommend the adoption of the described interleaver as channel interleaver for 3GPP.

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# 1.0 Introduction

In this memo, we propose to use a fully optimized Algebraic Interleaver to achieve maximum interleaving depth and time span at 1st interleaving stage in order to cope with fading environments. In order to support the rate matching after the 1st interleaving, such an Algebraic Interleaver possesses a good random spreading property to allow the straightforward rate matching (i.e. puncturing and repetition). The major advantages of this interleaver among its robustness to fading is a very simple implementation, and a maximum flexibility. This allows to consider any evolution of the span of either first or second interleaver and adaptation to other items considered today in 3GPP, as simple and flexible introduction of DTX scheme in downlink, multiframe multiplexing, etc....

The design principles is to map the multiple coded-blocks from channel encoder output, of the TrCHs of the same QoS into a 2-dimensional matrix and then apply linear congruential rules to permute the rows and columns of such a matrix. The maximum interleaving depth and time span can be achieved by searching a set of best parameters.

In 3rd generation CDMA system, the multi-media services are multiplexed in transport channels to perform channel coding, interleaving and spreading. Based on the very flexible channel interleaver with optimum performance, we propose a universal service multiplexing and channel interlaving scheme.

# 2.0 Interleaver description

## 2.1 First Interleaver Algorithm

To make the Algebraic Interleaver simple, we use the following matrix permuting rules:

**STEP-1**: Convert a $N_c^{Tr}$ 10 ms coded blocks (each with length $N$ coded symbols) into a block matrix

For $N_c^{Tr} = 1, 2, 4, 8$, we use $N_r = \lfloor N/\gamma \rfloor$ , and, if Nr is less than 10, a $N_r \times 8$ block matrix with $\gamma = [8, 4, 2, 1]$ respectively; if Nr is greater than 10, a N*1 matrix.

**STEP-2**: Do matrix row and column permutation based on the following rules:

| | |
|---|---|
| Row Permutation | $I_r(k) = [\alpha_r k + e(l)] mod N_r$ |
| Column Permutation | $I_c(l) = [\alpha_c l + f(k)] mod N_c$ |

where the parameter $\alpha_r$ is chosen as the largest prime number less than $\lfloor N_r / \log_2(\log_2(N_r)) \rfloor$, the parameter $\alpha_c$ is chosen as the largest prime number less than $\lfloor N_c \rfloor$, the function $e(l) = ml + [N_r + 1] mod 2$, where parameter $m = \lfloor N_r / N_c \rfloor + \lfloor N_r / N_c \rfloor mod 2$ , the function $f(k) = 2k + [N_c + 1] mod 2$. The prime numbers table to consider to get the largest primes is (1, 3, 5, 7, 11). Note that $\alpha_c$ is 7.

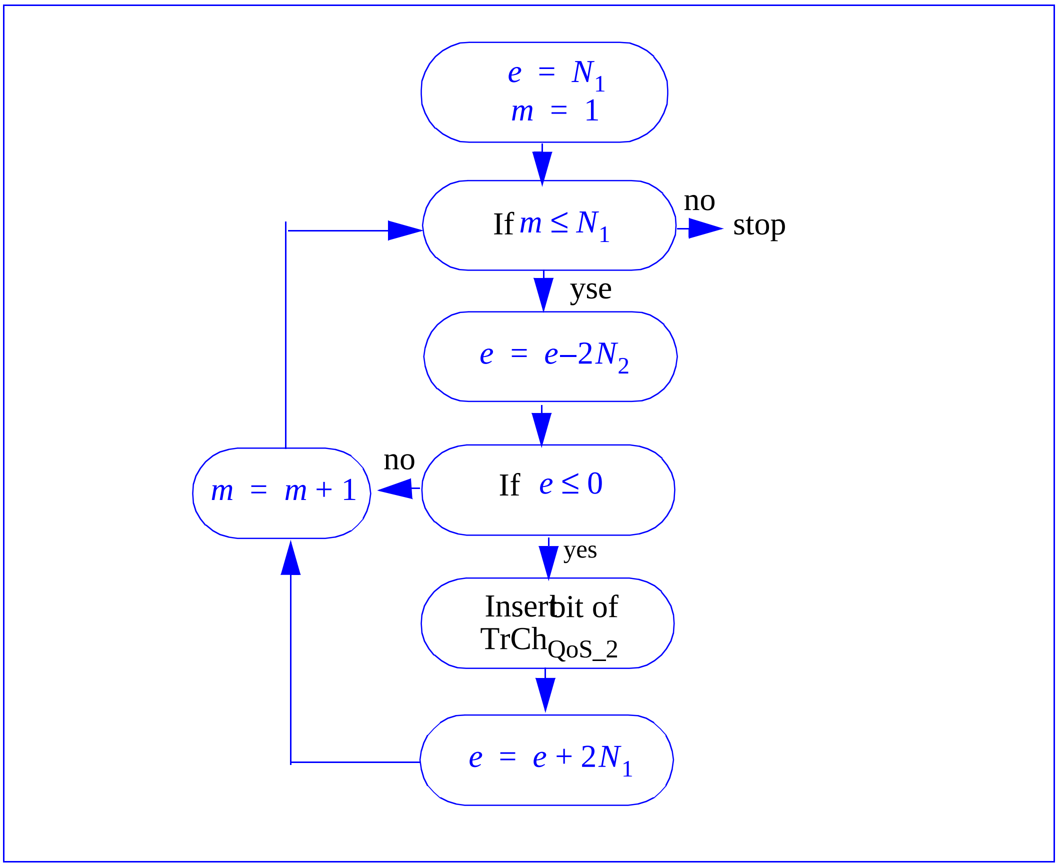
## 2.2 Second interleaver description

If the 2nd Interleaver is not designed properly, it can degrade the 1st Interleaver resulting in an overall poor performance. This issue has been identified and extensively discussed. One solution is to design 2nd Interleaving as shuffling bits evenly from different Transport Channels. Multiplexing of all TrChs, which occurs before this second interleaving, is assumed to consist of aggregation of bits of these TrChs in each 10ms block.

Since at 1st-stage interleaving, the interleavers are optimized for each data stream with different QoS, by using a simple shuffling operation which can interlace interleaved data with different QoSs, the spreading property of each QoS interleaved stream can be preserved. It will even be improved due to insertion of bits from others TrCHs inbetween bits of one TrCHs, puting the bits even further apart while not changing their order in one TrCh. Due to the randomization effect of Algebraic interleaving, multiplexing, shuffling, physical channel segmentation and DPCH mapping will not degradate the 1st stage interleaving performance.

Suppose we have two streams of the interleaved radio frames from the service multiplexing block in Figure 1. Let first frame be denoted as $TrCh_{QoS\_1}$ with $N_1$ bits and second frame be $TrCh_{QoS\_2}$ with $N_2$ bits, and assume $N_1 \geq N_2$, then the shuffling algorithm can be expressed in Figure 5.

**FIGURE 1. Shuffling Algorithm**




*This shuffling process can be continued in a recursive fashion to shuffle the other* $TrCh_{QoS}$.

## 2.3 Recommended puncturing scheme in uplink

In uplink, rate matching is performed after channel interleaving.

Because of the randomised output of the first optimised interleaver the symbols are uniformly distributed. Block puncturing is recommended in this case due to the good distance properties of the bits in one line of the interleaver matrix.

If the configured default puncturing rate for the TrCh is $R_p$, then $P = \lfloor R_p \times N_r \rfloor$ rows of interleaved matrix should be deleted,

1. Block puncture of  interleaver output:

   Delete $I_r(k)$ rows $k = 1, 2 \ldots P$

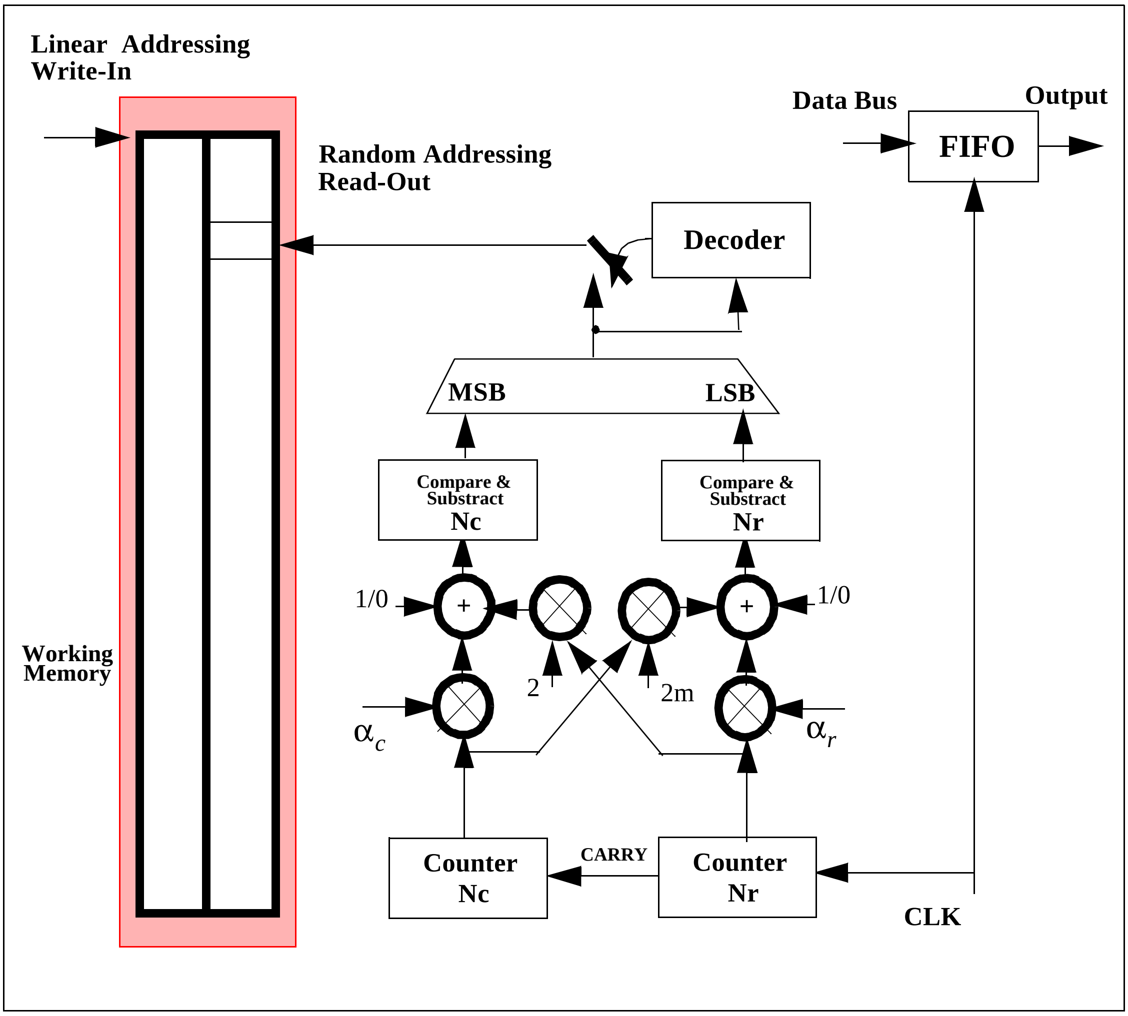
2. If in one frame less than the configured rate has to be punctured because of the abscence of some other TrCh which was multiplexed, then the first bits of the line that was selected for default punturing rate.

# 3.0 Advantages of proposed channel interleaver

## 3.1 Low complexity of De-Interleaving and Implementation of Channel Interleaver

One of the most interesting feature for the proposed Algebraic channel interleaver is that *the deinterleaver is the same as the interleaver*. In addition, the algebraic interleaving address can be generated on-the-fly. Such an interleaver structure allows a very simple hardware implementation, see Figure 1.

**FIGURE 2. Implementation of Algebraic Interleaver**



## 3.2 Flexibility to Adapt to Arbitrary Interleaving Size

If we chose the interframe interleaving range from 1 to 8 frames, with $N_c = (1 or 8)$, then by Euclid's Division Lemma, for any interleaving size $N$, we can find the matrix row number $N_r$, such that $N = N_r N_c + r$, where $\cdot = \{0, \ldots 7\}$, these additonal addresses should be deleted to match arbitrary interleaving frame size. It is straightforward to see that maximum number of such index deletions is 8 addresses. This index deletion for frame size matching can be implemented by an address decoder in conjuction with a pre-filled FIFO with a depth of 8 symbols. See Figure 1.

## 3.3 Robustness to puncturing

One of the issues of the 3GPP uplink channel interleaver is how to avoid consecutive puncture of adjacent symbols of the coded blocks from the channel encoder output. This is important to ensure the performance of the channel decoder, especially in the case when Turbo coding is employed.

In general, the Algebraic interleaver can guarantee that the distance of adjacent punctured symbol is maximized for a one line puncturing of the matrix. At this point, for higher puncturing rate it is recommended to use block puncturing if more than one line of the matrix has to be punctured.

The other advantage is that no particular puncturing grid or algorithm has to be used to perform puncturing. Puncturing scheme stays very simple.

Puncturing can be performed on a frame by frame basis by not puncturing some positions if in some frame less puncturing than the default is to be applied, because of the lower rate of TrCH multiplexed by default.

This puncturing scheme might be enhanced further by using uniform puncturing algorithm with the help of de-interleave operation.

## 3.4 Robustness to fading

The main objective of channel interleaver is to allow the consecutive faded symbol at decoder input to be spread as far as possible by de-interleaving. It can be seen by the simulation results in the following section.

## 3.5 Integration in the 3GPP coding, interleaving and multiplexing chain

- This interleaver scheme provides the possibility to define other interleaver spans if needed without any modification, for example 30ms, 50ms....if this is proved to be useful. There is no constraint either first or second interleaver span due to the use of a simple formula for interleaving.

- Multiframe multiplexing is currently discussed as a method for Slotted mode in some adhoc groups of WG1. This sheme would imply a larger second interleaver span. If it is adopted, the proposed interleaver scheme will cope with it without any modification, due to the simplicity and flexibility of second interleaver.
- In the same way, this interleaver scheme gives the possibility to have wider span of second interleaving in case all TrChs have a transmission time interval higher and if this increases the performance.
- Today for downlink, the possibility of grouping DTX at the end of the slots or of the frame is required as Working Assumption. It can be handled by the proposed interleaver right away, be it at the end of the slots or of the frames. No dummy bits need to be inserted before the interleaver since the interleaver can operate on any frame size. Both first and second interleaver would then operate on “real” bits only. Then these bits are mapped on the physical channel, leaving some room either at the end of the slots or of the frames according to the scheme selected. Then DTX could be applied at the end of the chain, after channel interleaving, and physical channel mapping to the empty part of the frame.
- This shows that the proposed scheme can cope with DTX in a straight forward way without need for any dummy bits insertion.
- By avoiding the need for dummy bits, and their artificial interleaving, the proposed scheme permits to avoid multiple on/off power transitions, which will be better in terms of PA.
- The proposed scheme allows also to change dynamically between positioning of the DTX at the end of the slots or at the end of the frames according to the system needs.

## 3.6 Future proofness

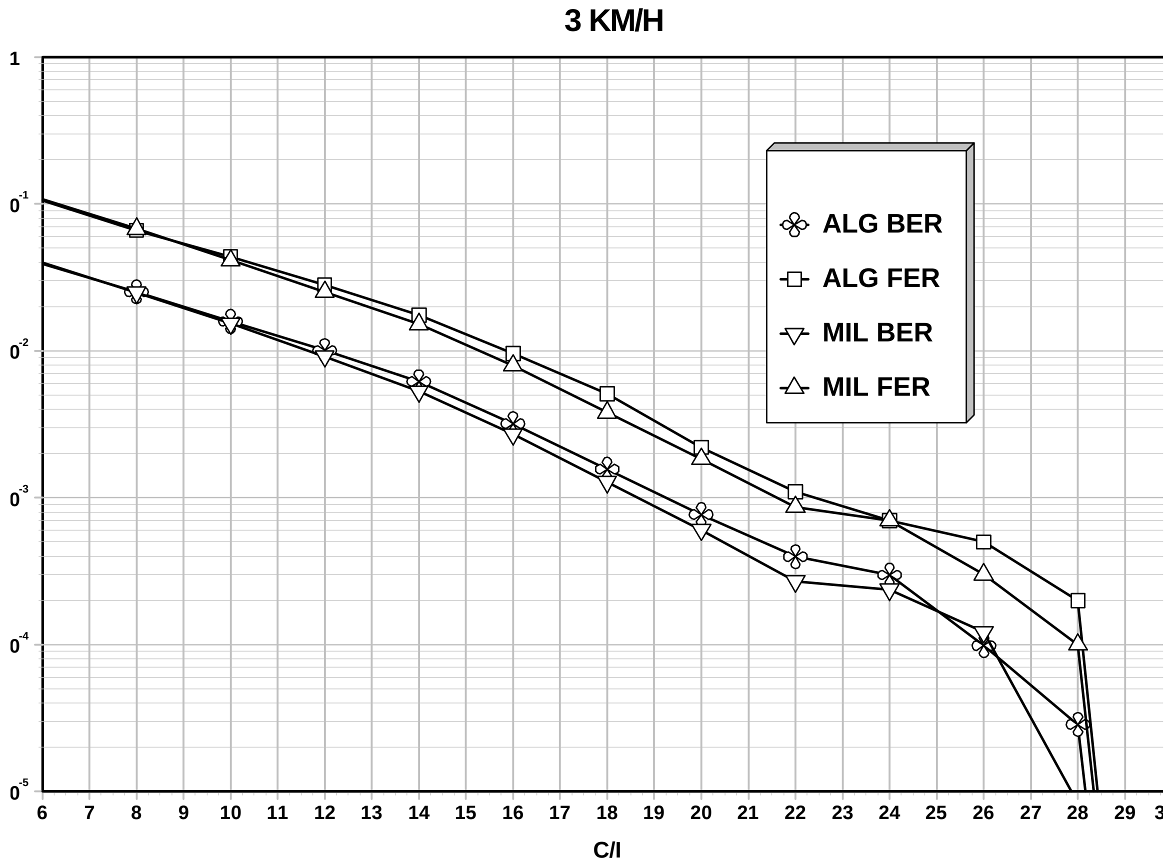
Thanks to the use of a formula to define the interleaver indexes, this interleaver will naturally cope with all frames sizes defined in the future without any need for defining new index tables or patterns specific to frame sizes.

In the same way, any rate of puncturing can be applied withour the need to re-define some specific puncturing patterns.

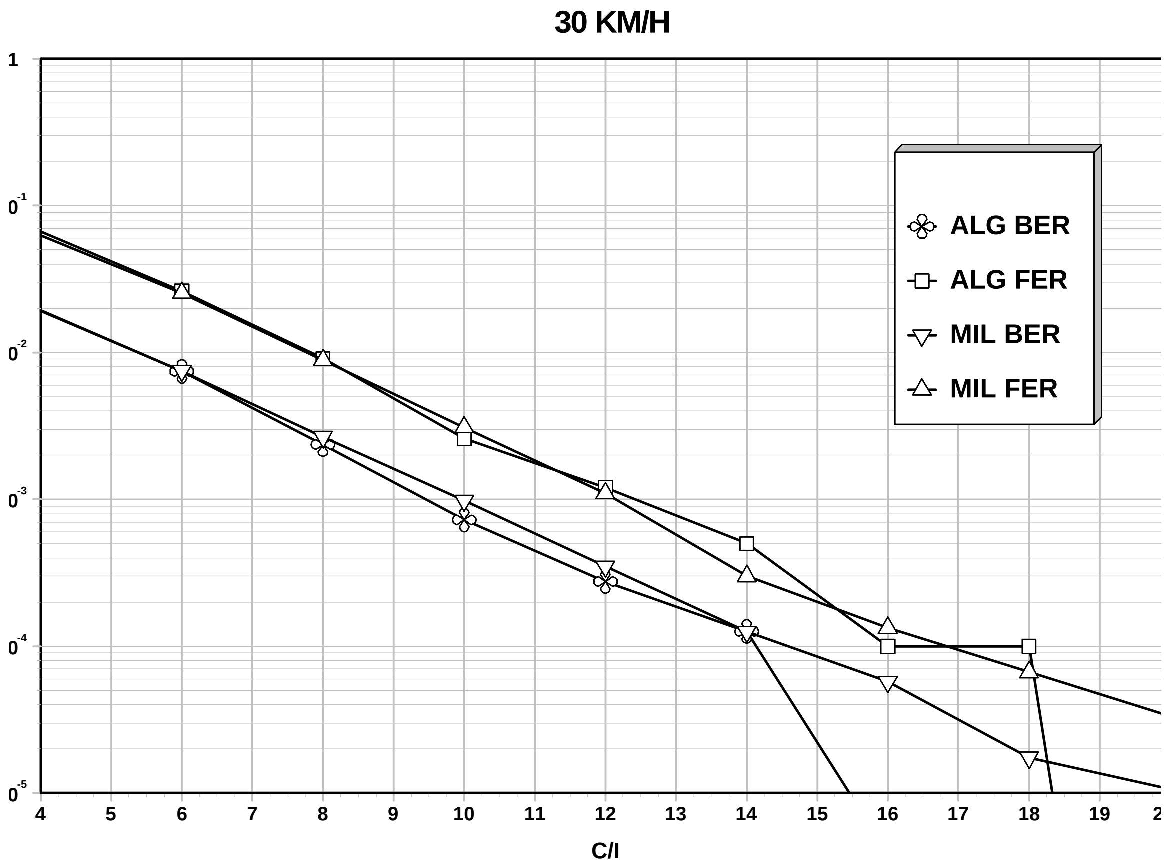
In this respect, it is claimed that this interleaver will adapt smoothly to any evolution of the whole chain of Transport Channel Coding, Rate Matching and Multiplexing.

# 4.0 Performance

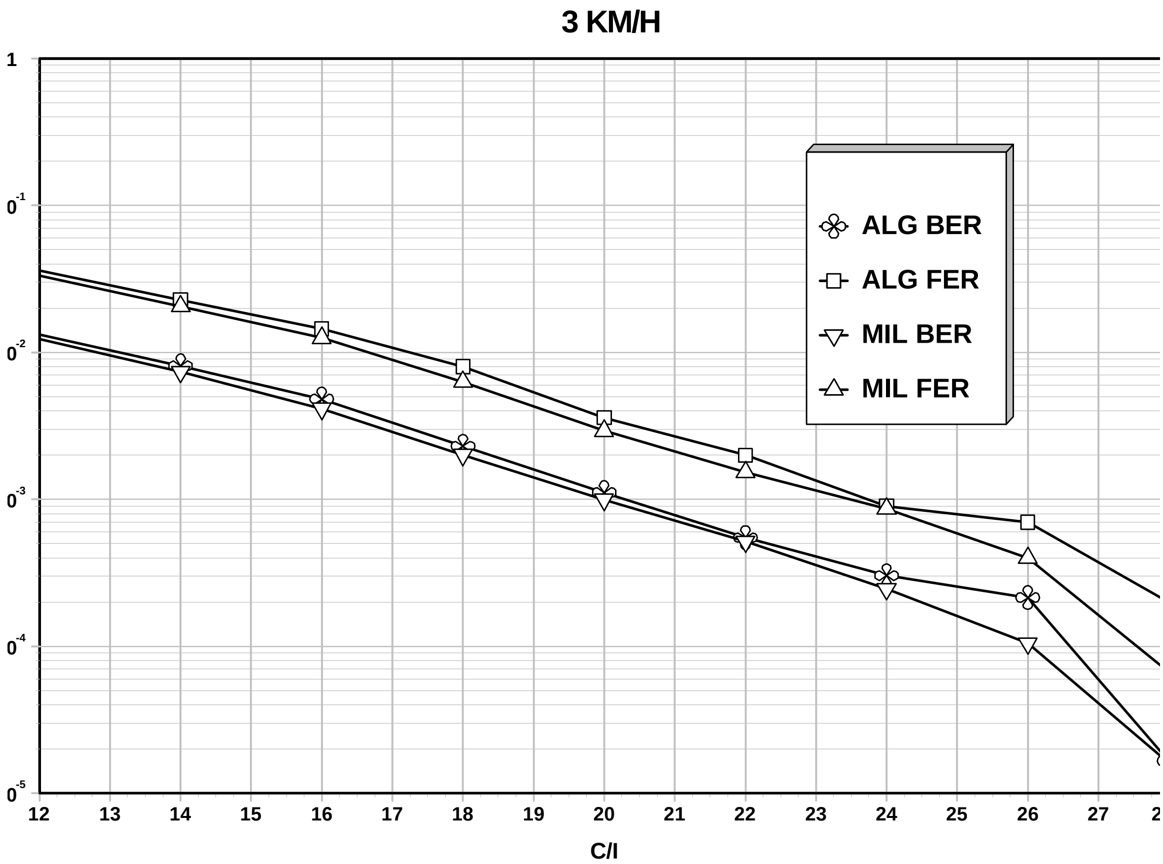
## 4.1 Format 1 - 3km/h



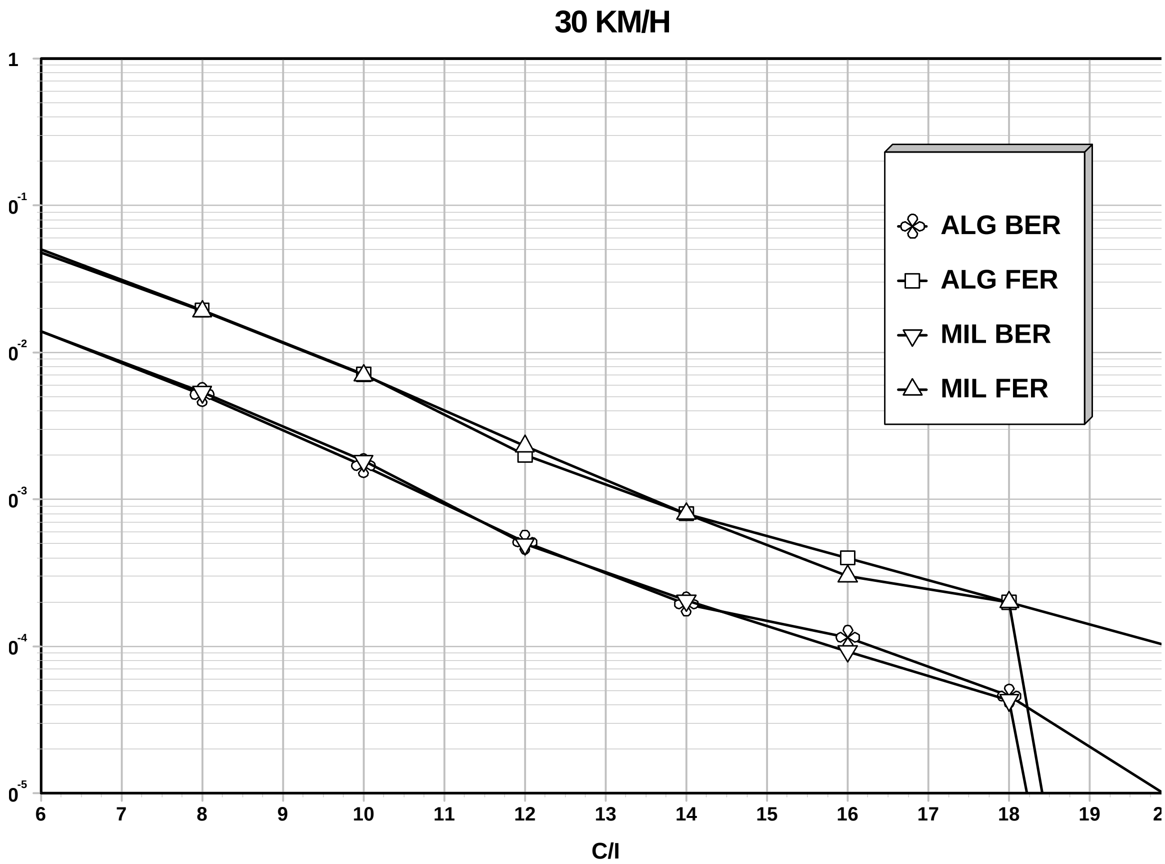
## 4.2 Format 1 - 30km/h



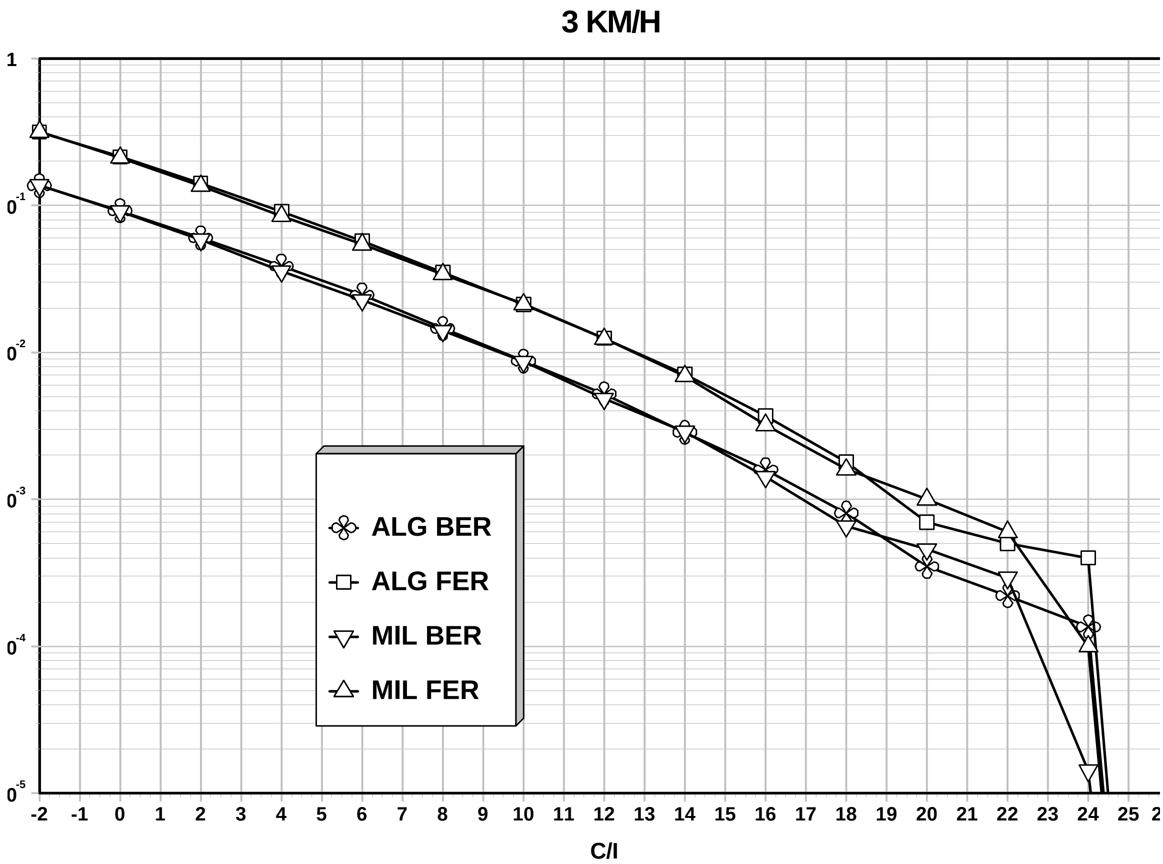
## 4.3 Format 2 - 3 km/h



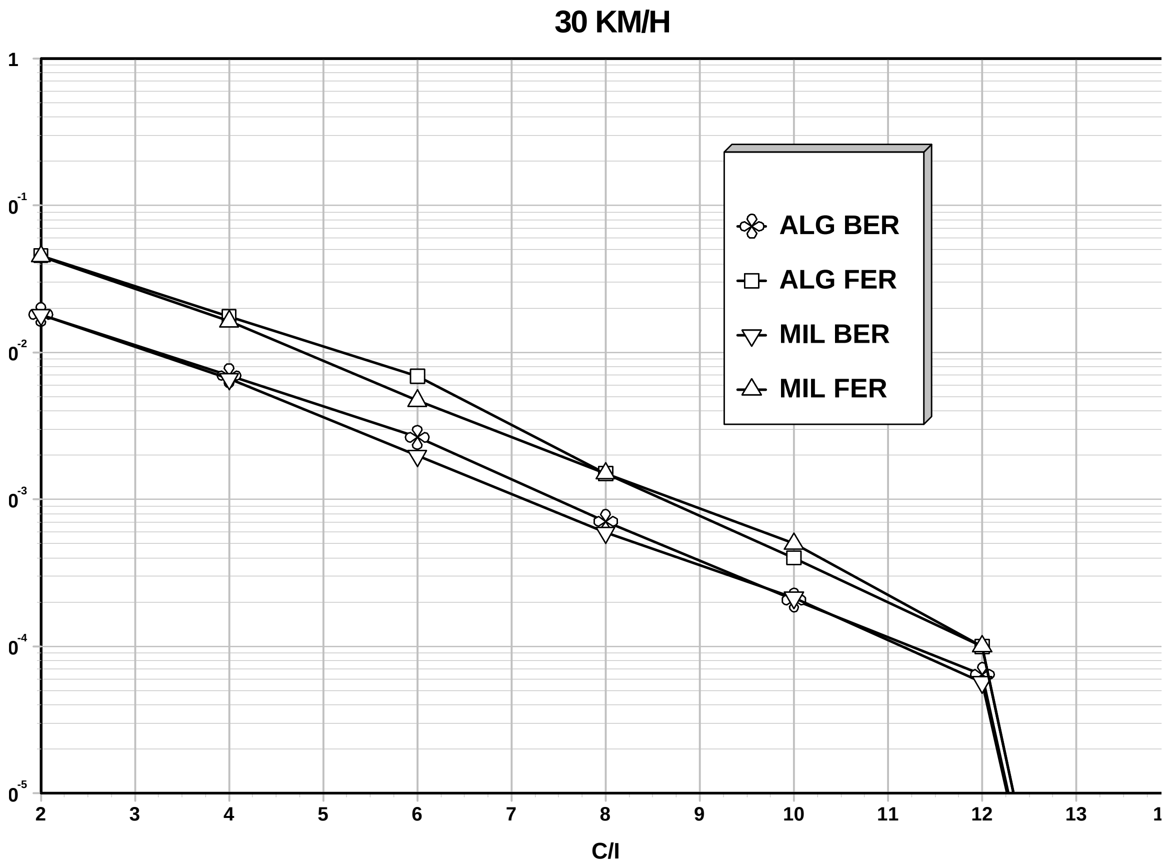
## 4.4 Format 2 - 30km/h



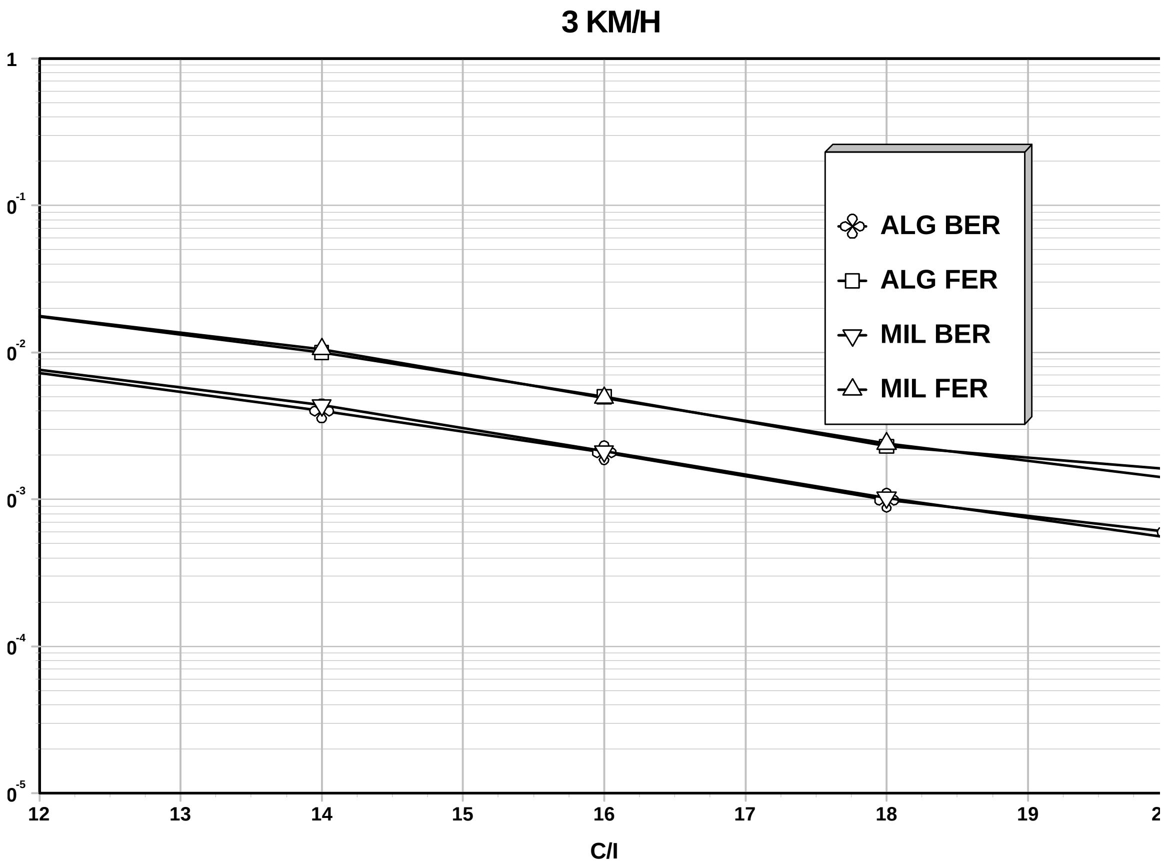
## 4.5 Format 7 - 3km/h



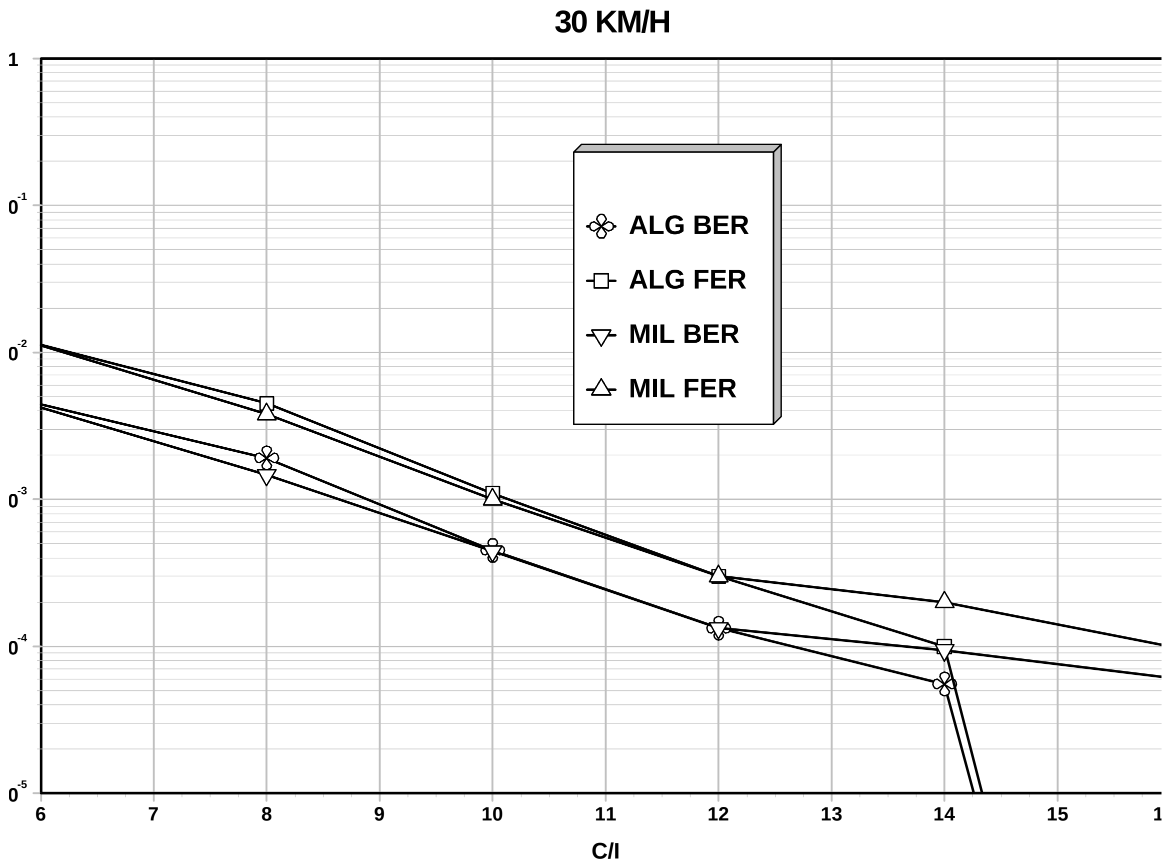
## 4.6 Format 7 - 30km/h



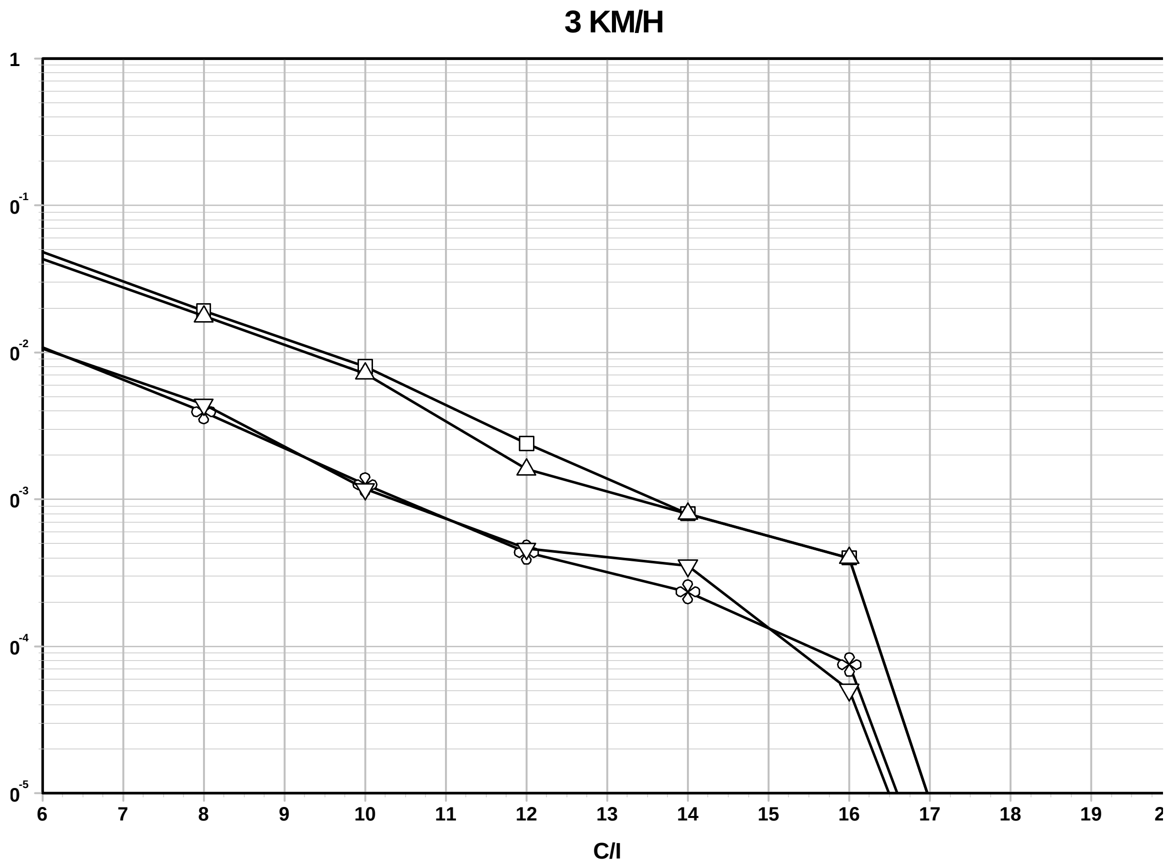
## 4.7 Format 8 - 3km/h



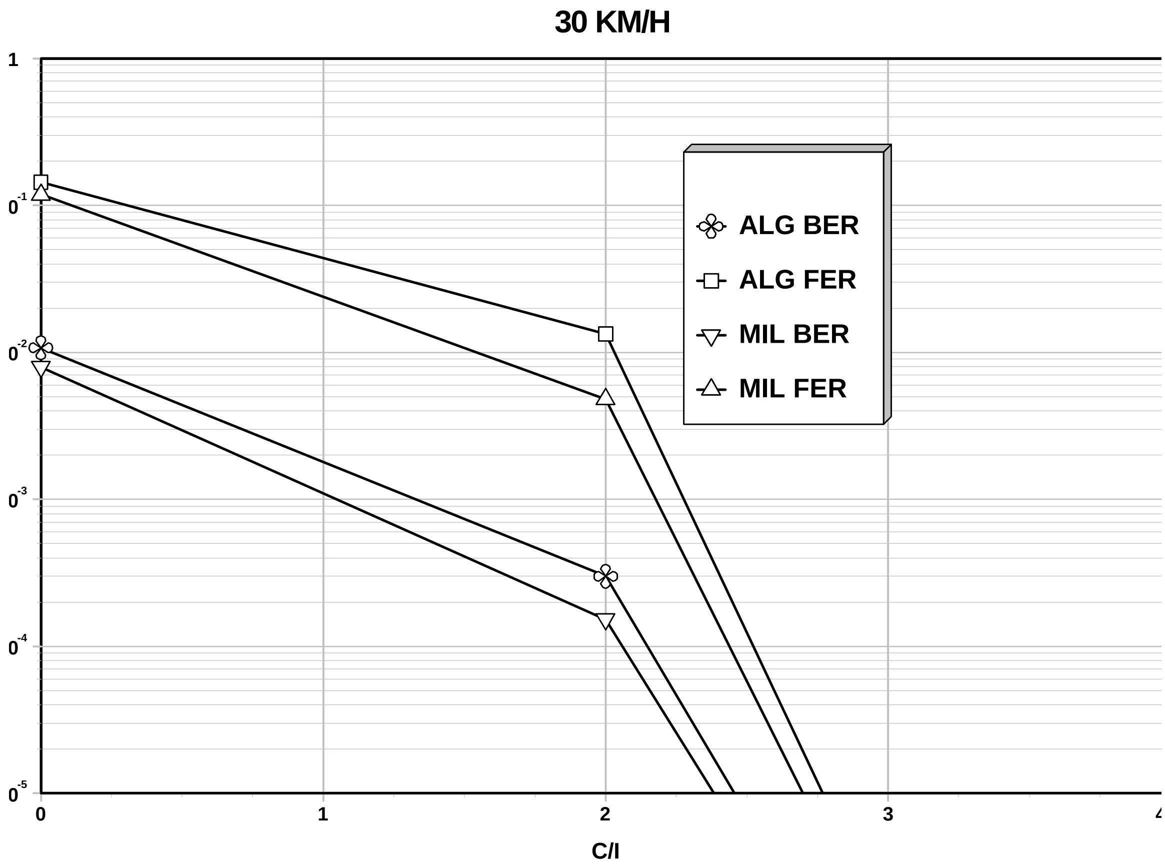
## 4.8 Format 8 - 30km/h



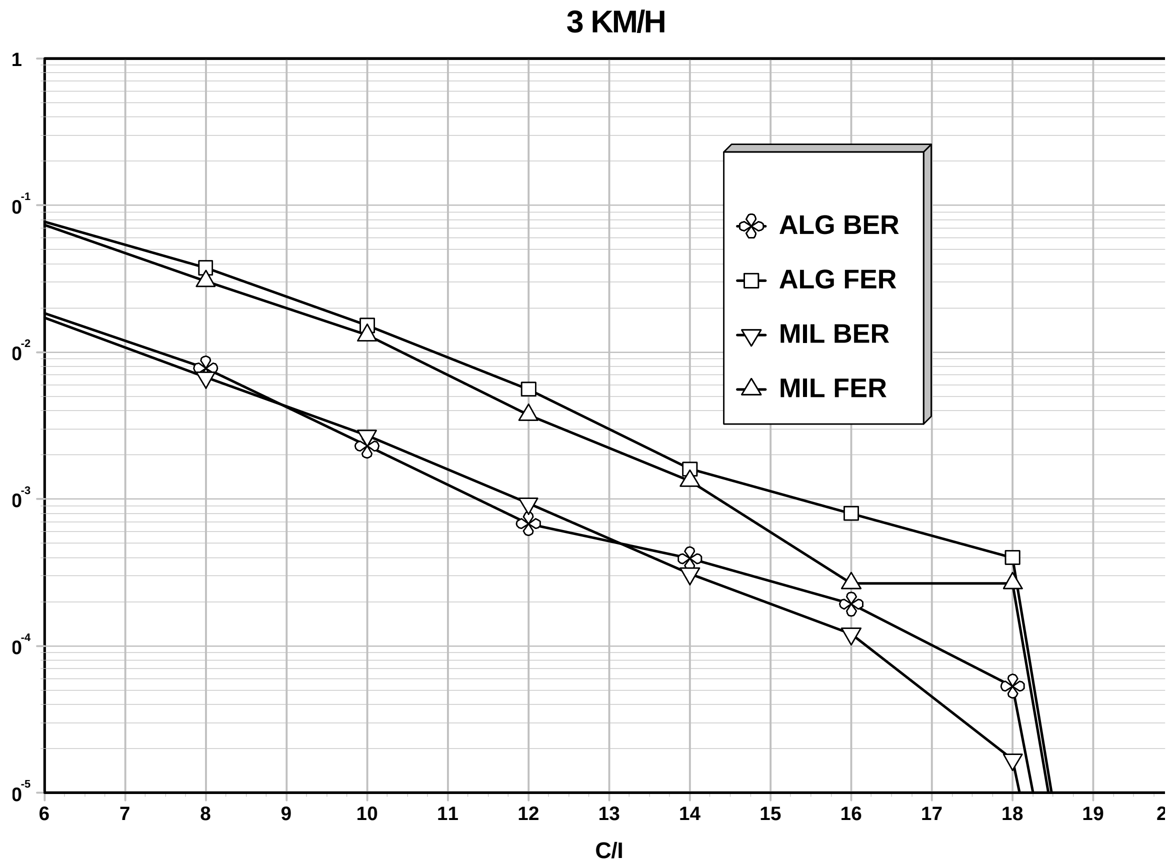
## 4.9 Format 17 - 3km/h



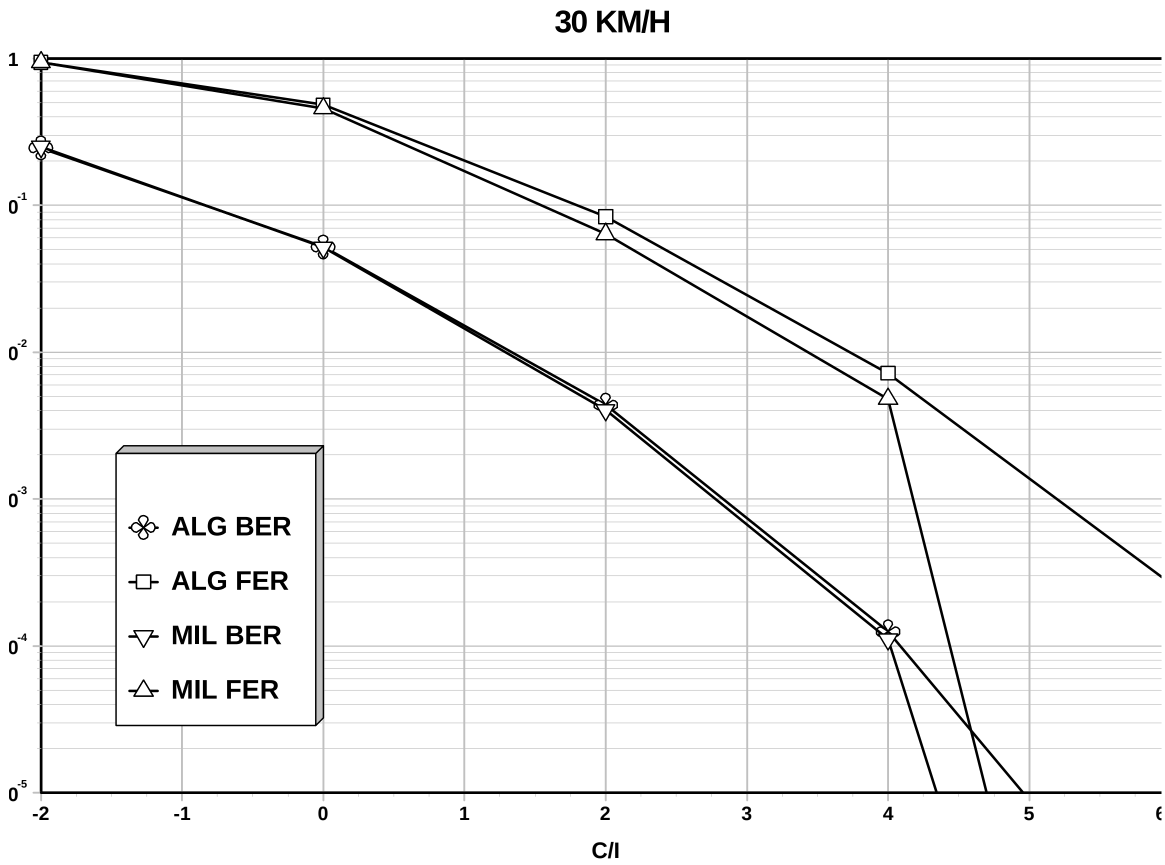
## 4.10 Format 17 - 30 km/h



## 4.11 Format 18 - 3km/h



## 4.12 Format 18 - 30km/h



# 5.0 Conclusion

In this document, we proposed a channel interleaver scheme which has a very low complexity, a great flexibility towards frame sizes and DTX design, which is robust towards fading and puncturing, and does not need to have specific puncturing patterns or algorithmdefined. It is also remarkably  future proof due to the use of a formula instead of index tables storage.

Therefore we recommend that this channel interleaver is adopted for UTRA in 3GPP.