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Technical Report

Terrestrial Trunked Radio (TETRA); Study of the suitability of the GSM Adaptive Multi-Rate (AMR) speech codec for use in TETRA

Reference

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Keywords

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ETSI

650 Route des Lucioles
F-06921 Sophia Antipolis Cedex - FRANCE

Tel.: +33 4 92 94 42 00 Fax: +33 4 93 65 47 16

Siret N° 348 623 562 00017 - NAF 742 C
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Contents

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Foreword

This Technical Report (TR) has been produced by ETSI Project Terrestrial Trunked Radio (TETRA).

The present document provides the performance results of an investigation into the suitability of the GSM Adaptive Multi-Rate (AMR) speech codec for use in TETRA.

The content of the present document is subject to continuing work within EP-TETRA and may change following formal EP-TETRA approval.

1 Scope

The present document provides background information on the performance of four modes of the GSM Adaptive Multi-Rate (AMR) speech codec operating within the TETRA system. The aim of the present document is to provide information to illustrate the behaviour of the GSM AMR in different TETRA operational conditions.

2 References

For the purposes of this Technical Report (TR), the following references apply:

[1] ITU-T Recommendation P.861: "Objective quality measurement of telephone-band (300-3400 Hz) speech codecs".

[2] ETSI ETS 300 395-2: "Terrestrial Trunked Radio (TETRA); Speech codec for full-rate traffic channel; Part 2: TETRA codec".

[3] ITU-T Recommendation G.191: "Software tools for speech and audio coding standardization".

3 Definitions and abbreviations

3.1 Definitions

For the purposes of the present document, the following terms and definitions apply:

Adaptive Multi-Rate (AMR) codec: speech and channel codec capable of operating at various combinations of speech and channel coding (*codec mode*) bit-rates

Codec mode: bit partitioning between the speech and channel codecs

Codec mode adaptation: control and selection of the *codec mode* bit-rates

Error Patterns: result of offline simulations stored on files

NOTE: To be used by the "Error Insertion Device" to model the radio transmission from the output of the channel decoder and interleaver to the input of the deinterleaver and channel decoder

Gross bit-rate: bit-rate of the *channel* (7,2 kbit/s)

3.2 Abbreviations

For the purposes of the present document, the following abbreviations apply:

AMR	Adaptive Multi-Rate
C/I	Carrier-to-Interfere ratio
CRC	Cyclic Redundancy Check
CuT	Codec Under Test
FEC	Forward Error Correction [Coding]
GSM	Global System for Mobile communications
IRS	Intermediate Reference System
Mod. IRS	Modified IRS
Peak-PSQM	Peak Perceptual Speech Quality Measure – An average of the worst 10 frames PSQM values.
PSQM	Perceptual Speech Quality Measure
RCPC	Rate Compatible Punctured Convolutional [Coding]
TETRA	Terrestrial Trunked Radio
TDMA	Time Division Multiple Access

4 General

4.1 Work Requirements

It has been decided to evaluate the 4,75 kbit/s, 5,15 kbit/s, 5,9 kbit/s and 6.7 kbit/s modes of the 3GPP/GSM AMR Codec compared to the original TETRA Codec.

In order to make assessments across the coverage area, rather than in error-free conditions, it is necessary to provide a representative FEC scheme and inject soft channel bit errors with a TETRA modem and radio channel simulation. It was decided to base the FEC on a modification of the current TETRA codec FEC based using the same polynomials. Although ideally the perceived user speech quality of the speech should be the metric, it was decided to perform an initial objective study based upon ITU-T Recommendation P.861 [1].

4.2 The Tasks

1) Develop the 4,75 kbit/s, 5,15 kbit/s, 5,9 kbit/s and 6,7 kbit/s 3GPP/GSM AMR Codec FEC Schemes along with generic FEC encoding and decoding routines:-

   a) For the 4,75 kbit/s, 5,15 kbit/s, 5,9 kbit/s and 6,7 kbit/s 3GPP/GSM AMR Codec modes, obtain bit error sensitivity profile using ITU-T Recommendation P.861 [1] referenced to error-free decoded speech.

   b) Determine the Class 1, Class 2 and Class 3 bits for each mode using a 3-speech frame block.

   c) Determine the FEC Rates for the Class 1 and Class 2 bits for each mode.

   d) Develop the puncture patterns for the Class 1 and Class 2 bits for each mode.

   e) Develop the interleave pattern for the payload bits of each mode for the TDMA slot.

   f) Develop generic versions of the TETRA ccoder and cdecoder routines, along with the necessary definition files to implement the above FEC schemes, with provision to allow future codec rates to be defined as and when required. Functional equivalence with the existing ccoder and cdecoder routines should be demonstrated.

2) Develop the TETRA Single-Slot "Soft-Bit" Files (see note):

   a) Provide 8-bit "Soft" demodulator output files (+/- 127) of 1 million bits each for the following channels (~31 Mbytes total);

      i. Static Channel @ 4 dB to 10 dB in 1 dB steps.

      ii. Typical Urban 5 km/h @ 10 dB to 24 dB in 2 dB steps.

      iii. Typical Urban 50 km/h @ 10 dB to 24 dB in 2 dB steps.

      iv. Hilly Terrain 200 km/h @ 10 dB to 24 dB in 2 dB steps.

   b) Develop a 'C' utility to apply soft-bit errors to TETRA TDMA slot data as produced by ccoder.

3) Perform the Objective Evaluations:

   a) For a 8 kHz sampled, -26 dBov, Mod. IRS filtered (ITU-T Recommendation G.191 [3]) mixed-gender speech file of approx 2 minutes duration (2000 TDMA Frames) (75-80 % active speech) encode the speech with each of the CuTs.

   b) Perform FEC encoding and interleaving for each CuT.

   c) For each channel condition and each CuT, inject soft-bit errors, decode FEC, decode speech and obtain ITU-T Recommendation P.861 [1] scores referenced to time-aligned original speech.

4) Estimate the C/I for which intelligibility is still maintained for each of the channels and for each of the Codecs based upon informal listening.

5) Report Results.

NOTE: Task 2 requires a TETRA channel simulation and both TETRA modulator and demodulator simulations. These simulations are not readily available and will represent a large part of the work if written as part of this evaluation.

5 Initial Study of the TETRA Speech Codec

5.1 TETRA Codec FEC

For the original TETRA Codec, within a TDMA timeslot of payload 432 bits, conveying two 30 ms speech codec frames, 102 bits are unprotected (Class 0), 112 bits are protected using a 2/3 rate RCPC code (Class 1) and 60 bits are protected with a 8/18 rate RCPC code (Class 2). 4 tail-bits and 8 CRC bits are also encoded at the 8/18 rate.

Each TETRA Speech Codec frame comprises 137 bits. It was decided to perform an analysis of the TETRA speech codec in the presence of 10 % bit errors on each of these bits in-turn in order to ascertain whether the PSQM or Peak PSQM measure correlated well with the FEC classifications which were employed in the original TETRA FEC design.

For each of the 137 bit positions in the TETRA speech codec frame, 10 % errors were introduced into the bit stream produced by encoding 3 minutes of Mod. IRS filtered English speech encoded with the TETRA speech encoder. The PSQM and Peak PSQM distortion was measured according to ITU-T Recommendation P.861 [1] between the errored decoded speech and the error-free decoded speech.

The results of this exercise are shown in figures 5.1 and 5.2. For reference purposes, the frame error PSQM and Peak PSQM distortion figures for 10 % random and 10 % random pairs of speech frames are also presented (10 % random pairs introduces greater distortion).

5.2 PSQM or Peak-PSQM For Error Sensitivity?

In order to determine if PSQM or Peak PSQM provides are better indicator of Speech Class for the TETRA codec we ordered the distortion values in decreasing order of distortion and compared the predicted Class with the actual Class.

The curves for the two distortion measures are presented in figures 5.3 and 5.4.

Figure 5.3 shows that 11 of the 30 bits of Class 2 are incorrectly classified and 17 of the 51 Class 0 bits are also misclassified. Perhaps the most apparent outlier bit is bit 8 of LSF Vector 3 which is not grouped with the other bits misclassified from Class 2.

In contrast, figure 5.4 shows that only 8 of the 30 bits of Class 2 are incorrectly classified and 12 of the 51 Class 0 bits are misclassified. In addition, the misclassifications are well clustered and remain broadly in the correct order.

In conclusion, it seems reasonable to assume that the Peak PSQM of the Worst 10 frames is a better metric for defining the classes than the conventional PSM measure since it correlates better with the classifications used in the original TETRA Codec.

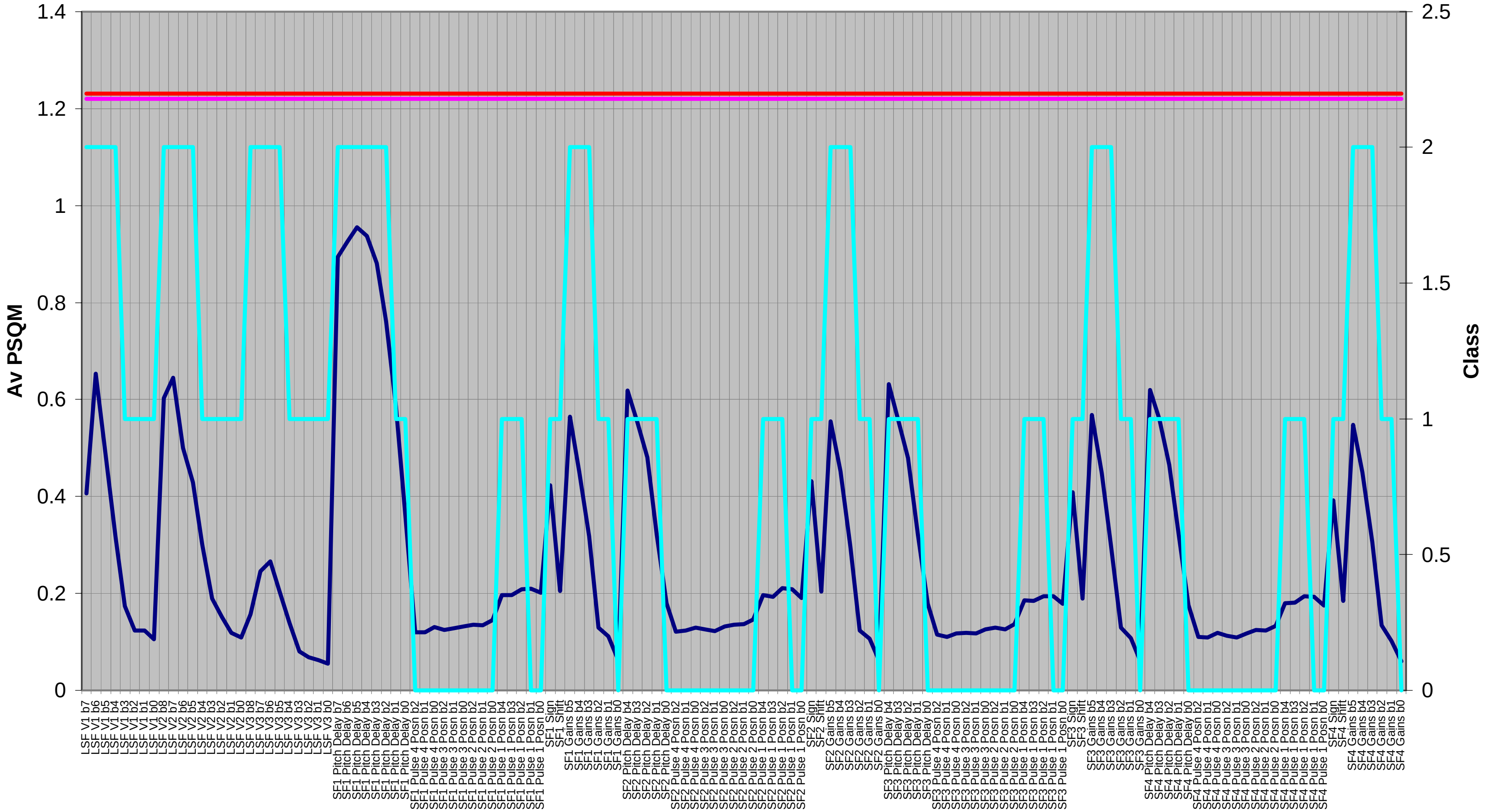

Figure 5.1: PSQM vs. Bit Definition for the TETRA Speech Codec in 10 % Random Bit Errors and 10 % Random Frame Erasures (Single Frames and Frame Pairs)

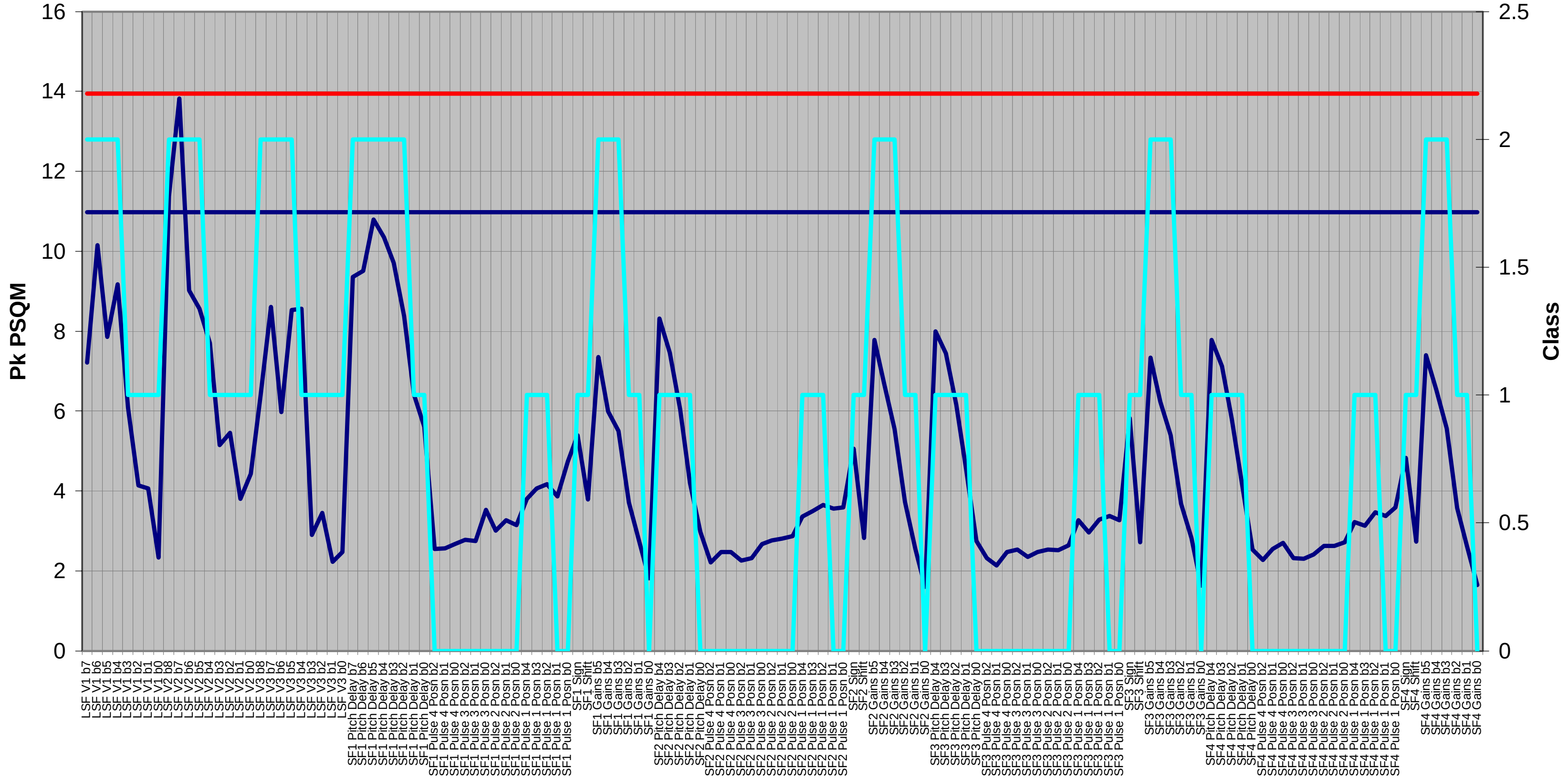

Figure 5.2: PeakPSQM vs. Bit Definition for the TETRA Speech Codec in 10 % Random Bit Errors and 10 % Random Frame Erasures (Single Frames and Frame Pairs)

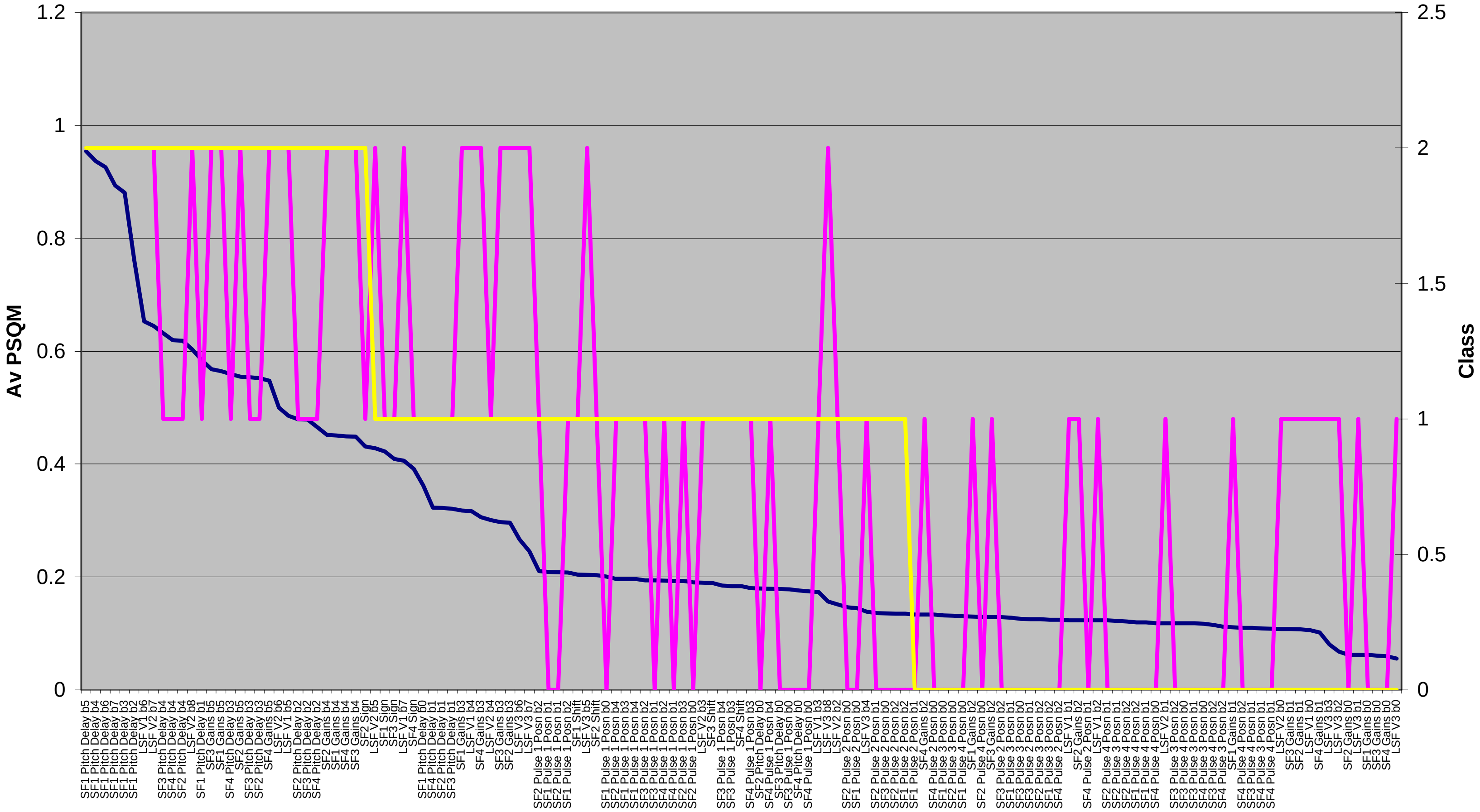

Figure 5.3: Ordered PSQM vs. Bit Definition and Class for the TETRA Speech Codec in 10 % Random Bit Errors

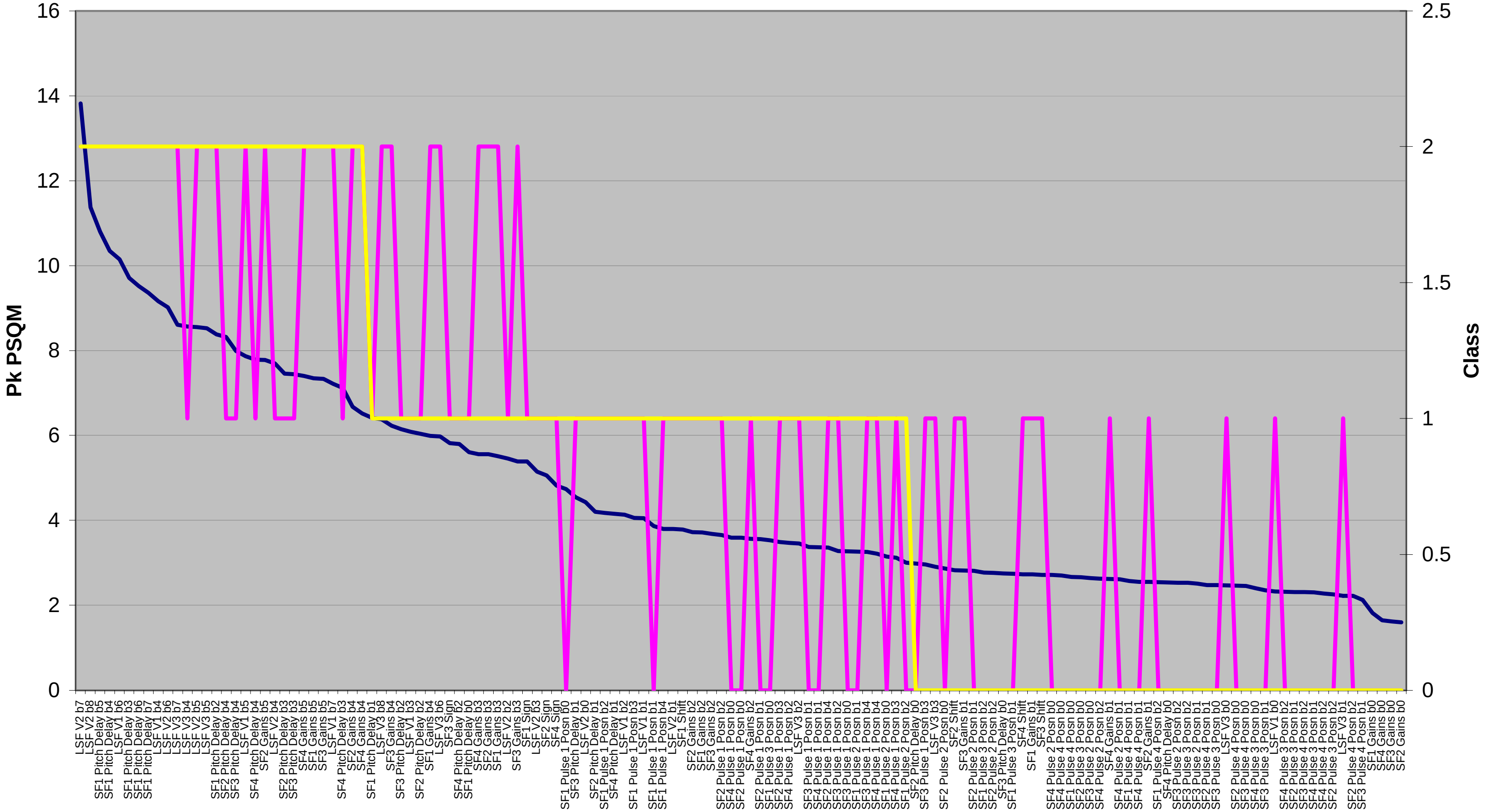

Figure 5.4: Ordered Peak PSQM vs. Bit Definition and Class for the TETRA Speech Codec in 10 % Random Bit Errors

6 PSQM Values for GSM AMR Codec

6.1 4,75 kbit/s Mode

See figures 6.1 and 6.2.

6.2 5,15 kbit/s Mode

See figures 6.3 and 6.4.

6.3 5,9 kbit/s Mode

See figures 6.5 and 6.6.

6.4 6,7 kbit/s Mode

See figures 6.7 and 6.8.

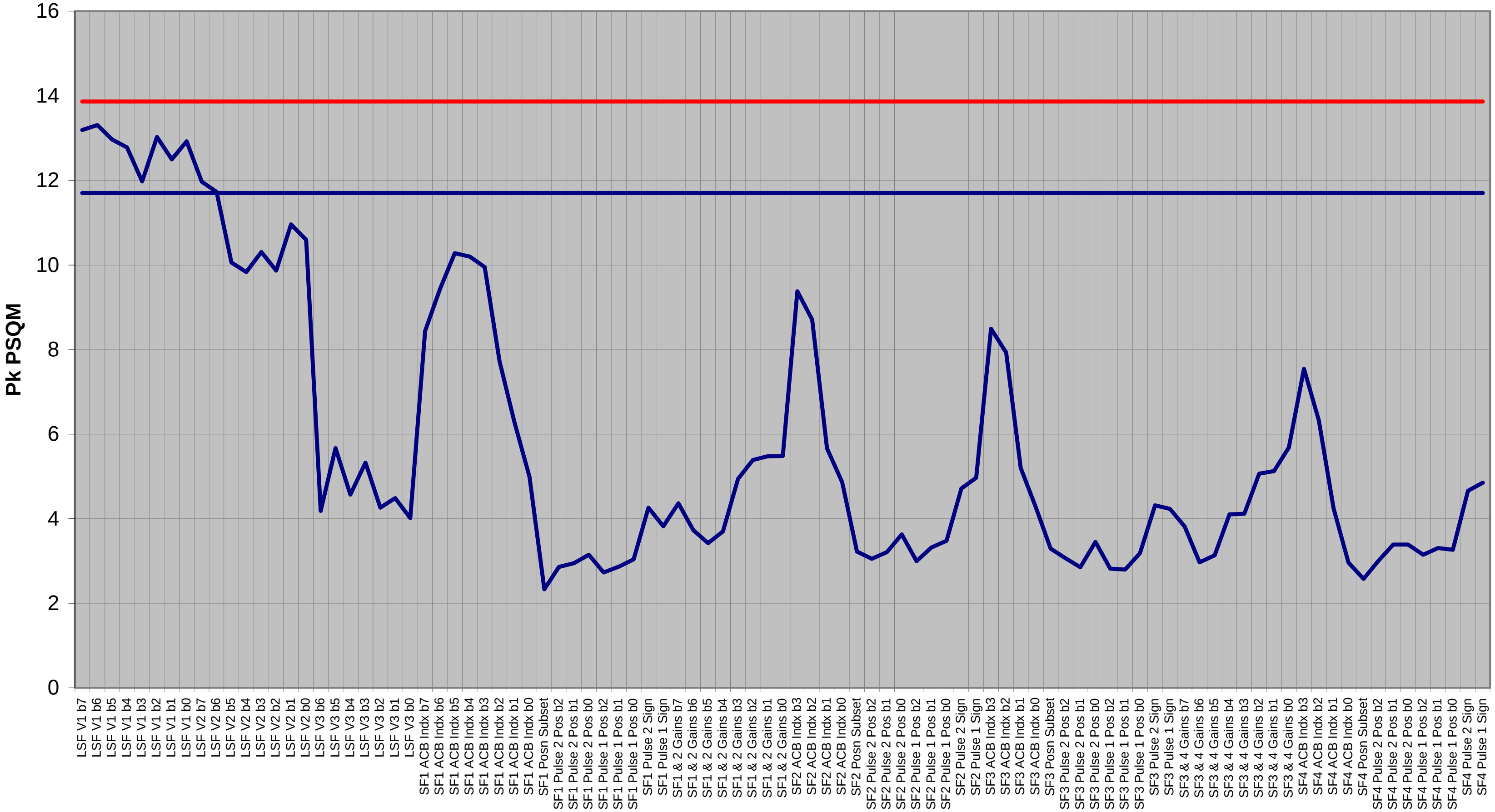

Figure 6.1: Peak PSQM vs. Bit Definition for the 3GPP/GSM AMR 4,75 kbit/s Mode in 10 % Random Bit Errors and 10 % Random Frame Erasures (Single Frames and Three-Frame Bursts)

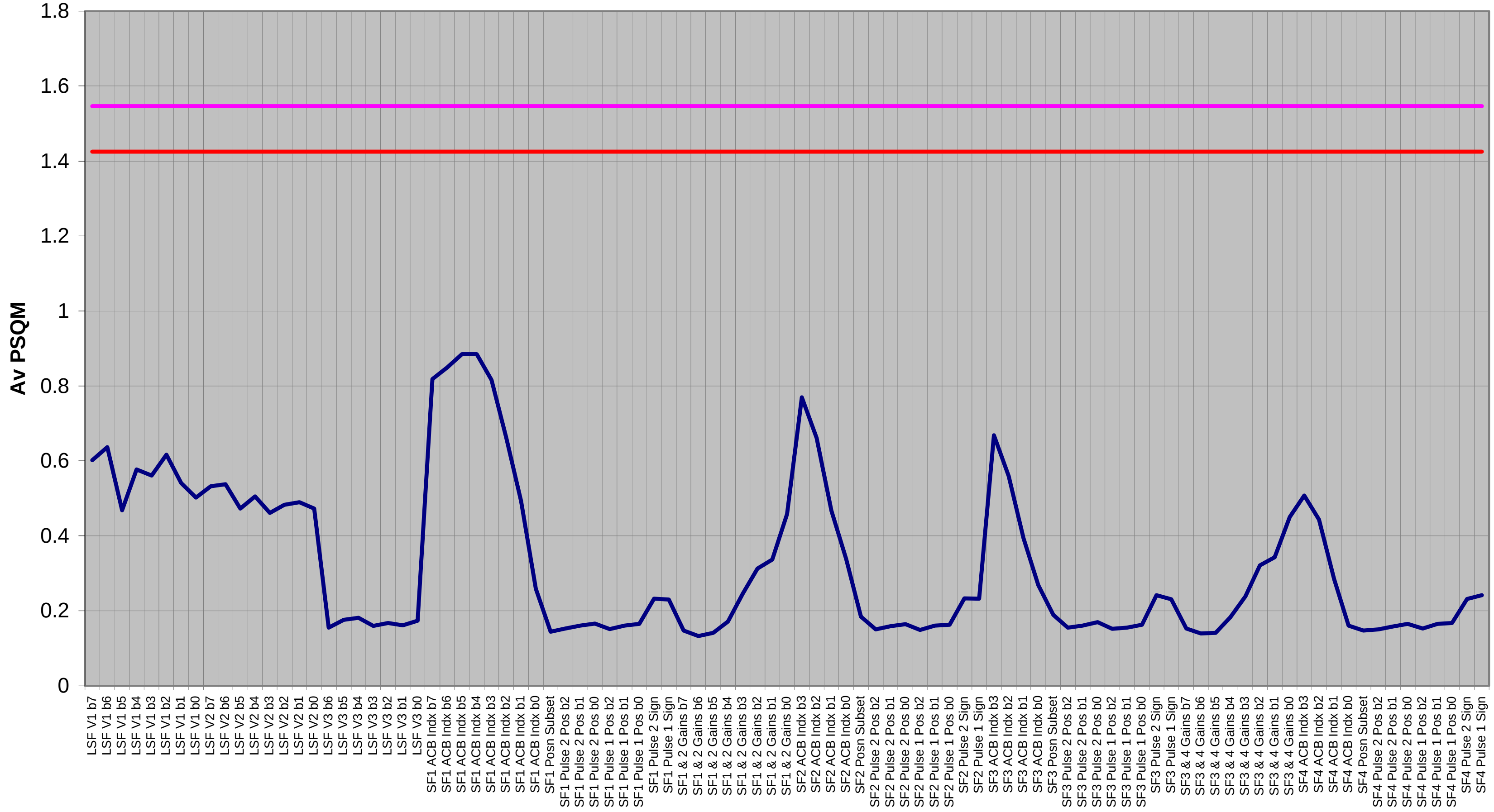

Figure 6.2: PSQM vs. Bit Definition for the 3GPP/GSM AMR 4,75 kbit/s Mode in 10 % Random Bit Errors and 10 % Random Frame Erasures (Single Frames and Three-Frame Bursts)

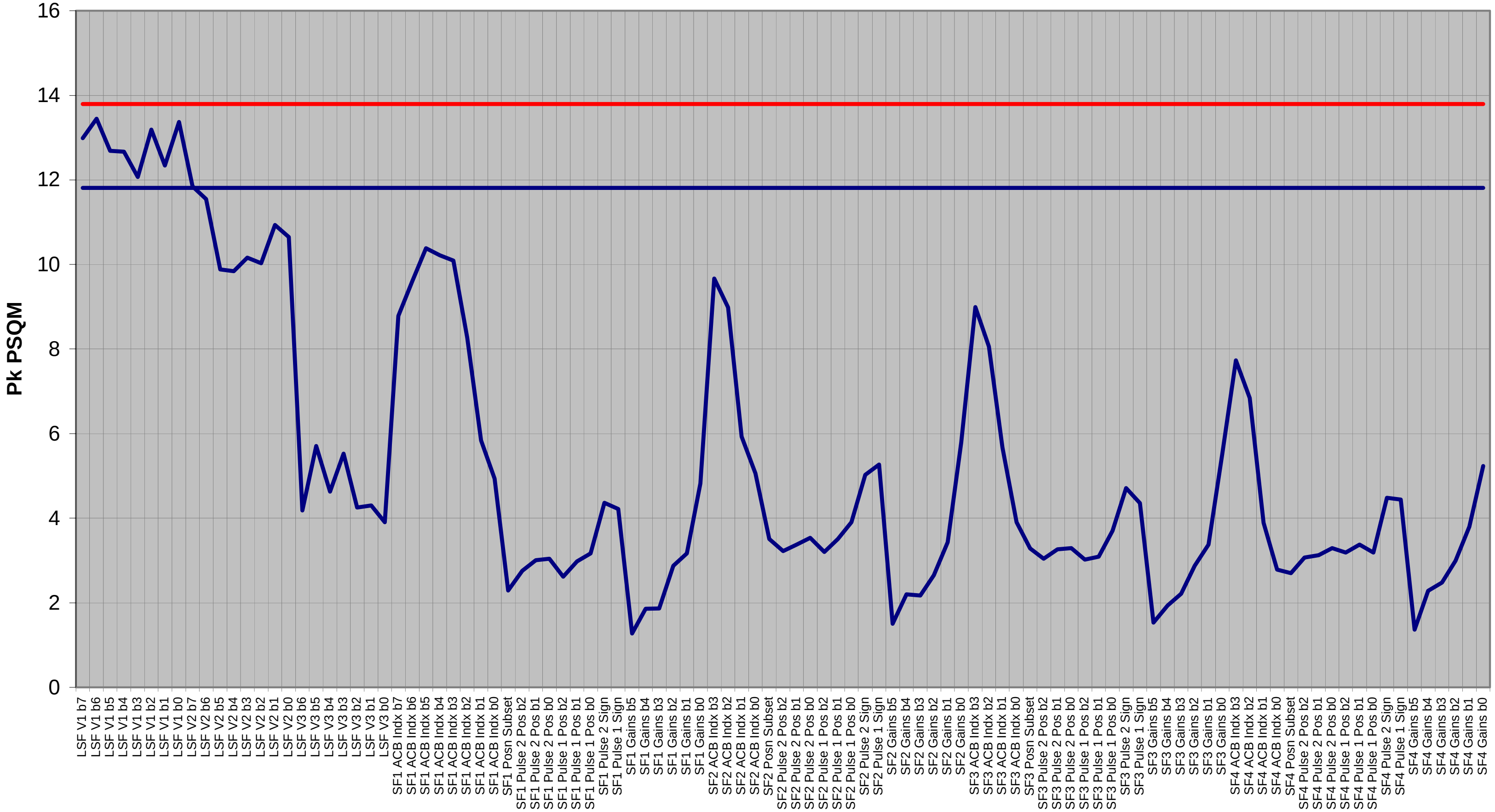

Figure 6.3: Peak PSQM vs. Bit Definition for the 3GPP/GSM AMR 5,15 kbit/s Mode in 10 % Random Bit Errors and 10 % Random Frame Erasures (Single Frames and Three-Frame Bursts)

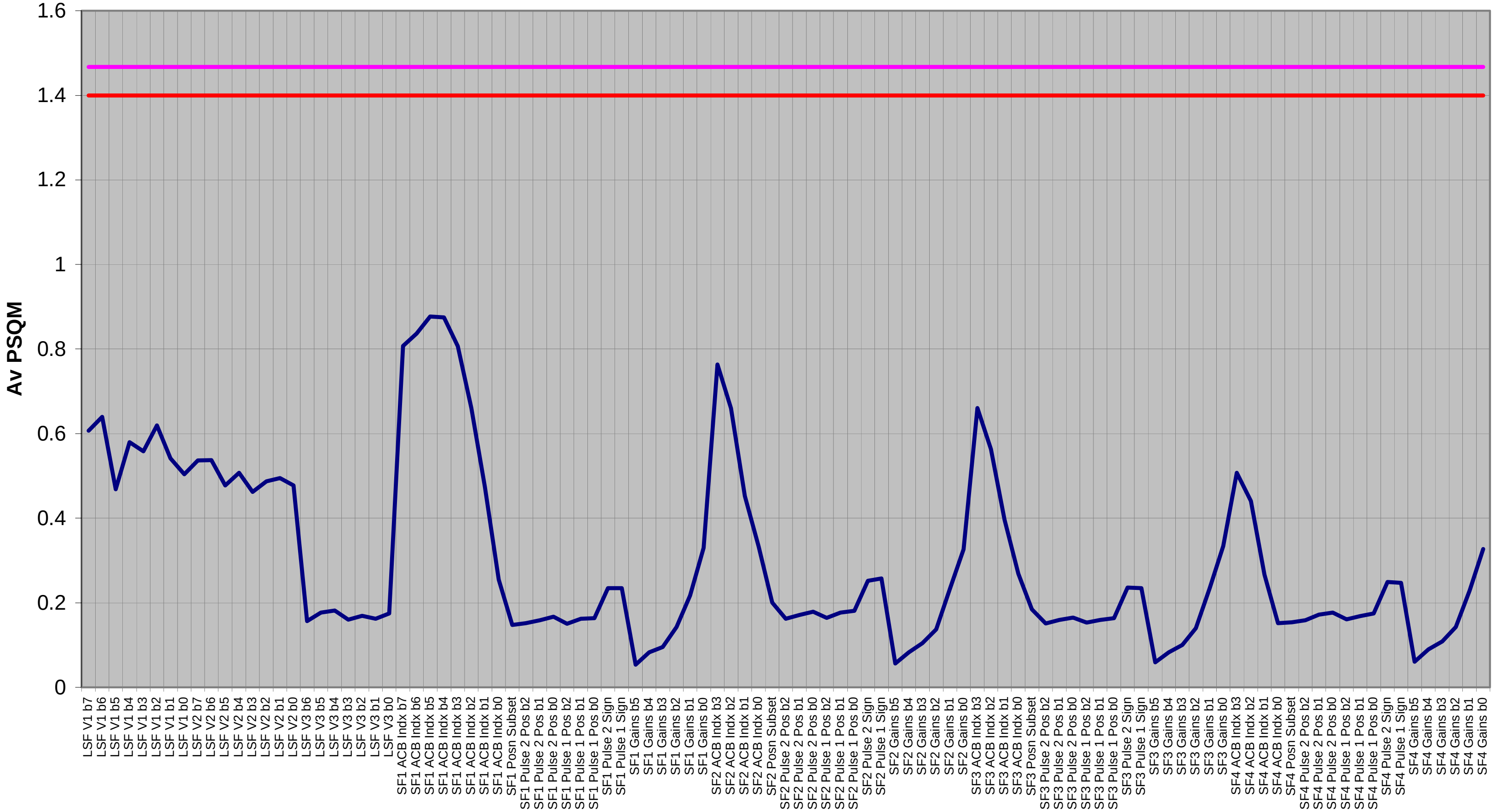

Figure 6.4: PSQM vs. Bit Definition for the 3GPP/GSM AMR 5,15 kbit/s Mode in 10 % Random Bit Errors and 10 % Random Frame Erasures (Single Frames and Three-Frame Bursts)

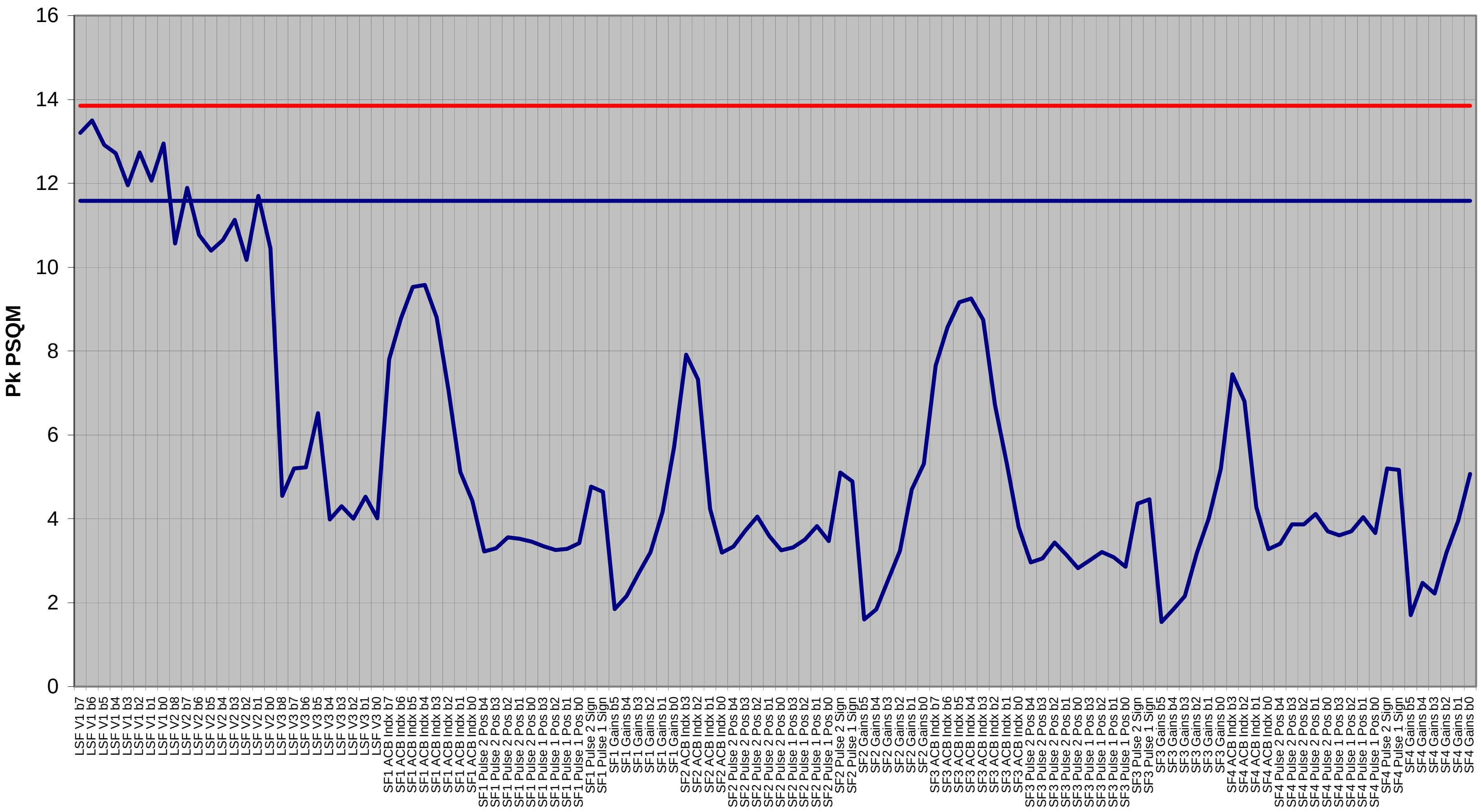

Figure 6.5: PeakPSQM vs. Bit Definition for the 3GPP/GSM AMR 5,9 kbit/s Mode in 10 % Random Bit Errors and 10 % Random Frame Erasures (Single Frames and Three-Frame Bursts)

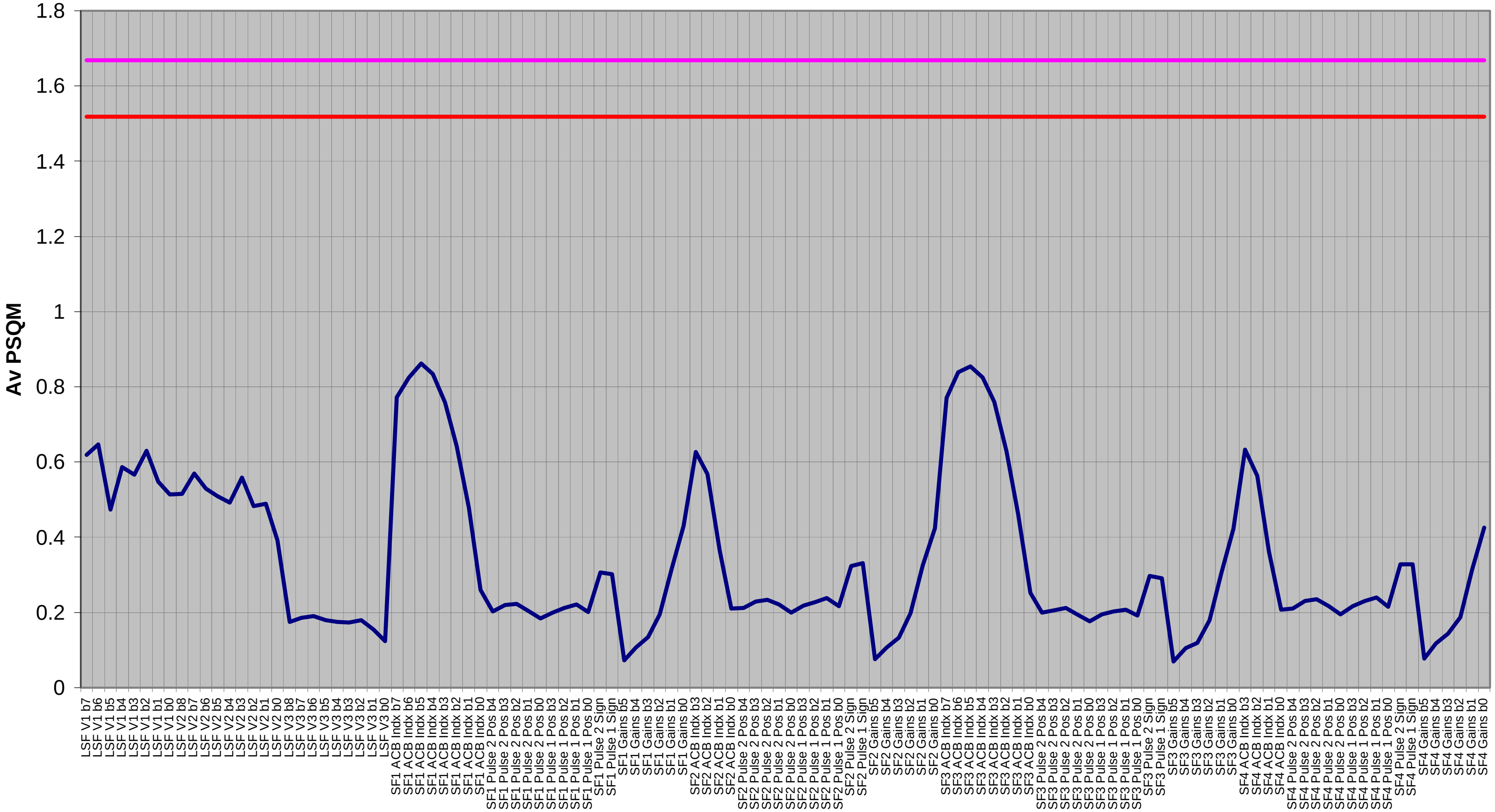

Figure 6.6: PSQM vs. Bit Definition for the 3GPP/GSM AMR 5,9 kbit/s Mode in 10 % Random Bit Errors and 10 % Random Frame Erasures (Single Frames and Three-Frame Bursts)

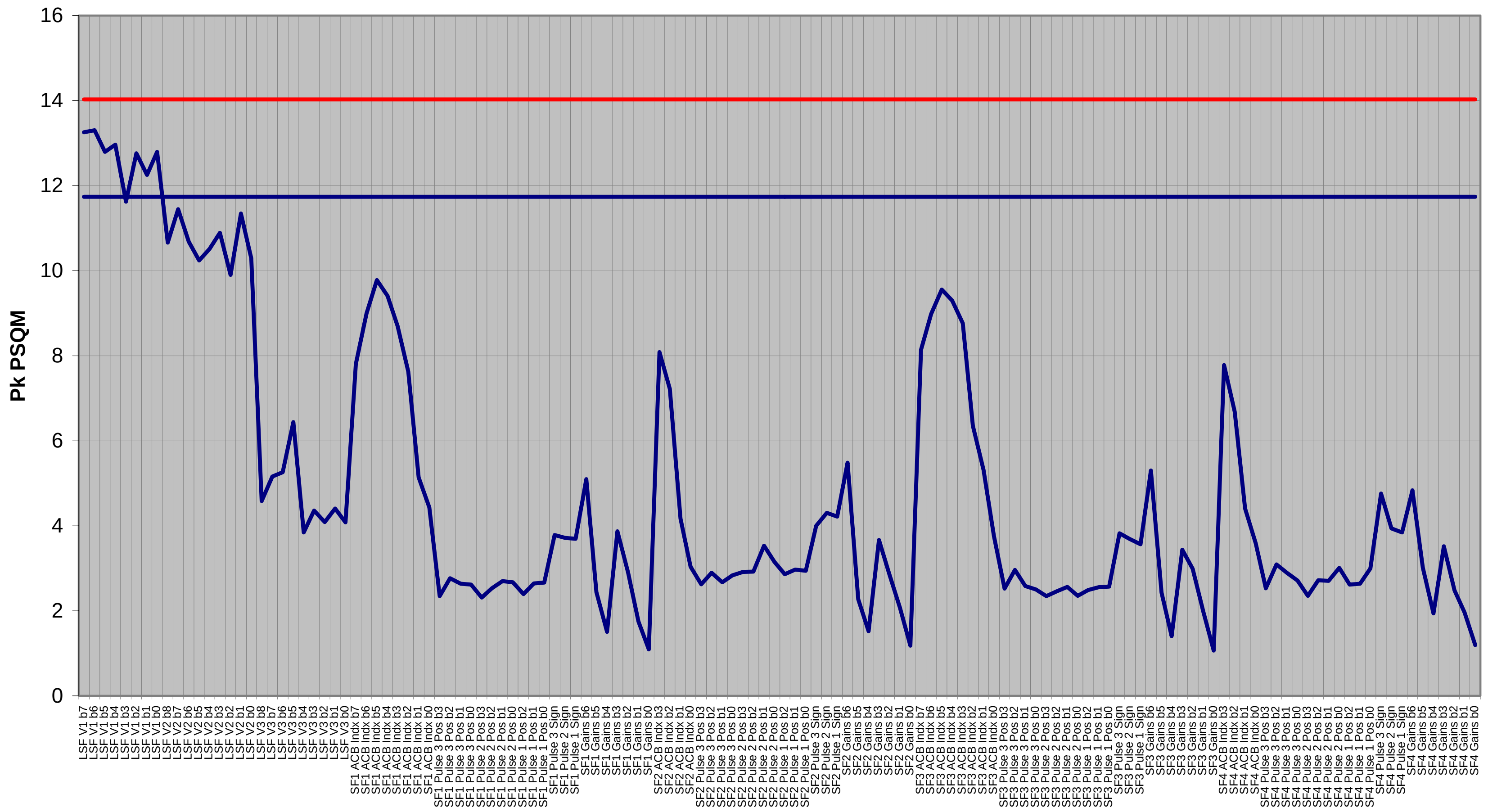

Figure 6.7: PeakPSQM vs. Bit Definition for the 3GPP/GSM AMR 6,7 kbit/s Mode in 10 % Random Bit Errors and 10 % Random Frame Erasures (Single Frames and Three-Frame Bursts)

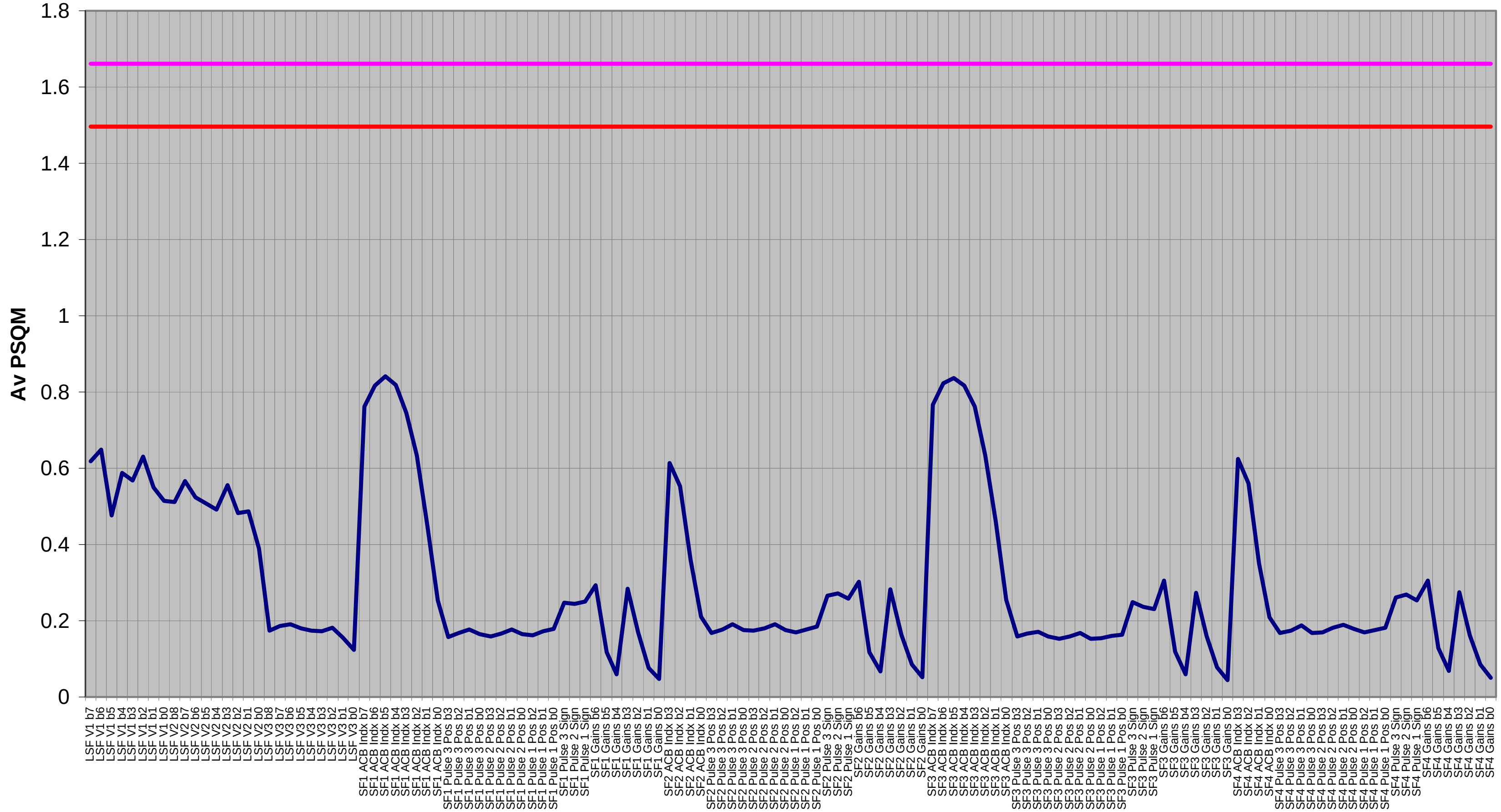

Figure 6.8: PSQM vs. Bit Definition for the 3GPP/GSM AMR 6,7 kbit/s Mode in 10 % Random Bit Errors and 10 % Random Frame Erasures (Single Frames and Three-Frame Bursts)

7 Initial FEC Bit Allocations for GSM AMR Codec

The FEC protection of each of the 3GPP/GSM AMR modes must use the same RCPC Polynomials and puncture patterns as the original TETRA Codec. This places some restrictions on the possible FEC permutations available at each speech codec bit rate.

Where the maximum FEC rate was set at 2/3 (Class 1 only), the Tail Bits of the RCPC Code and CRC bits were also encoded at the 2/3 rate.

At all times, the expected bit error profile of the RCPC decoding was anticipated in the allocation of bits. Where only Class 2 bits (R = 8/18) were used, the bits were ordered such that the most sensitive bits were placed at the start and end of the sequence. Where a combination of both Class 1 and Class 2 was employed, the Class 1 bits were ordered such that the most sensitive bits were placed at the beginning and end of the sequence with the least sensitive in the middle of the sequence and the Class 2 bits were ordered such that the most sensitive bits were sent at the end of the sequence nearer to the tail bits. The positioning of the CRC and tail bits was not altered from that employed in the TETRA standard.

7.1 4,75 kbit/s Mode

The basic options for the FEC protection of the 4,75 kbit/s mode are shown in figure 7.1 with the Peak PSQM sensitivities in descending order along with their bit definitions. The bit allocations are also shown in table 7.1. Each speech coder frame comprises 95 bits and three speech frames are packed into each TDMA frame.

The CRC was computed over the 60 most important bits in each TDMA frame for the 4,75 kbit/s mode.

Table 7.1: FEC Protection Options for the AMR 4,75 kbit/s Mode

Option	Class 0 Bits (R = 1)	Class 1 Bits (R = 2/3)	Class 2 Bits (R = 8/18)
1	27	60	8
2	9	86	0
3	45	30	20
4	63	0	32

7.2 5,15 kbit/s Mode

The basic options for the FEC protection of the 5,15 kbit/s mode are shown in figure 7.2 with the Peak PSQM sensitivities in descending order along with their bit definitions. The bit allocations are also shown in table 7.2. Each speech coder frame comprises 103 bits and three speech frames are packed into each TDMA frame.

The CRC was computed over the 60 most important bits in each TDMA frame for the 5,15 kbit/s mode.

Table 7.2: FEC Protection Options for the AMR 5,15 kbit/s Mode

Option	Class 0 Bits (R = 1)	Class 1 Bits (R = 2/3)	Class 2 Bits (R = 8/18)
1	51	44	8
2	33	70	0
3	69	14	20
4	75	4	24

7.3 5,9 kbit/s Mode

The basic options for the FEC protection of the 5,9 kbit/s mode are shown in figure 7.3 with the Peak PSQM sensitivities in descending order along with their bit definitions. The bit allocations are also shown in table 7.3. Each speech coder frame comprises 118 bits and three speech frames are packed into each TDMA frame.

The CRC was computed over the 60 most important bits in each TDMA frame for the 5,9 kbit/s mode.

Table 7.3: FEC Protection Options for the AMR 5,9 kbit/s Mode

Option	Class 0 Bits (R = 1)	Class 1 Bits (R = 2/3)	Class 2 Bits (R = 8/18)
1	96	14	8
2	78	40	0

7.4 6,7 kbit/s Mode

Due to the small number of FEC bits available for FEC protection of the 6,7 kbit/s mode, only one option was tried This is shown in figure 7.4 with the Peak PSQM sensitivities in descending order along with their bit definitions. The bit allocations are also shown in table 7.4. Each speech coder frame comprises 134 bits and three speech frames are packed into each TDMA frame.

The CRC was only computed over the 24 most important bits in each TDMA frame for the 6,7 kbit/s mode.

Table 7.4: FEC Protection Options for the AMR 6,7 kbit/s Mode

Class 0 Bits (R = 1)	Class 1 Bits (R = 2/3)	Class 2 Bits (R = 8/18)
126	8	0

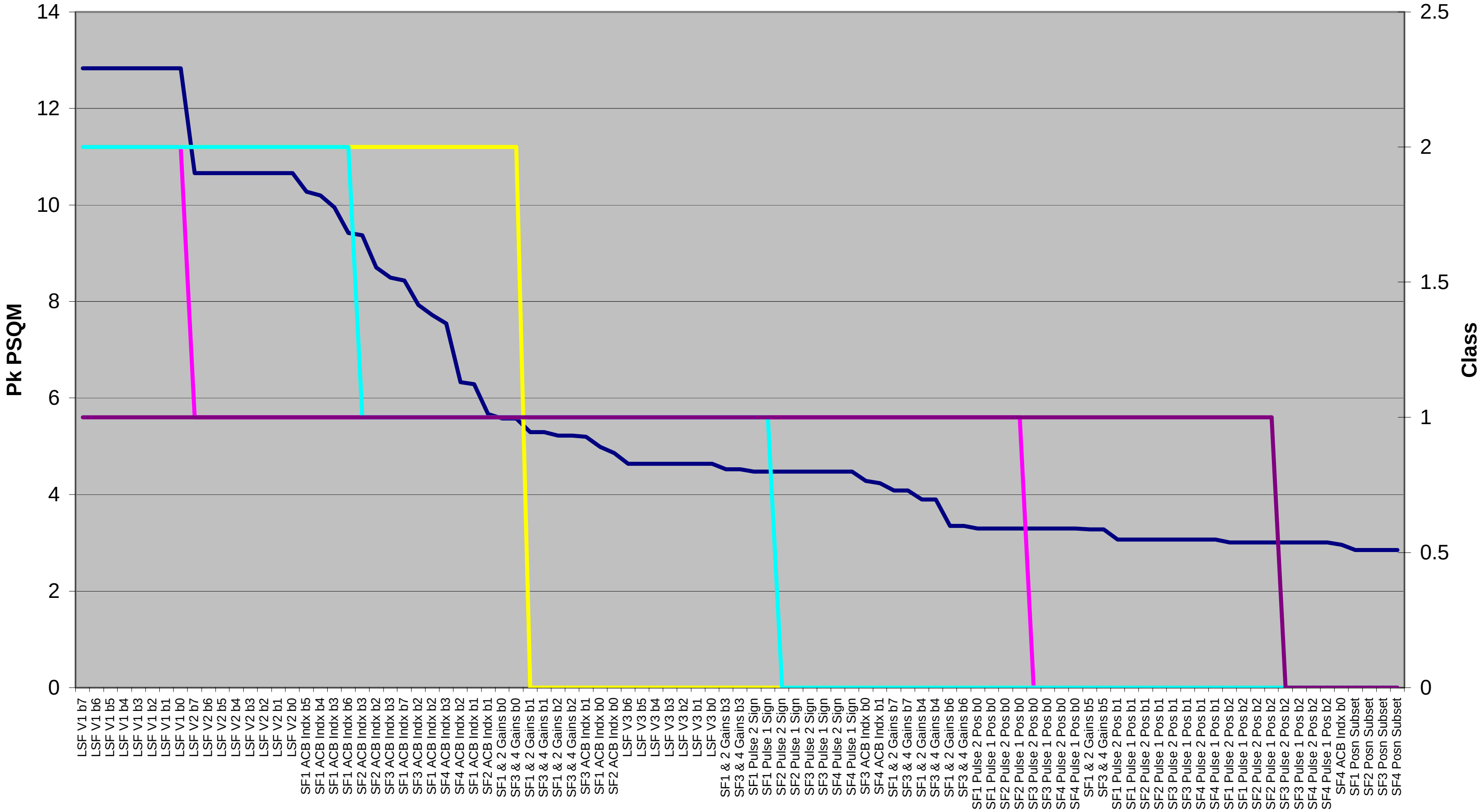

Figure 7.1: Ordered PeakPSQM and Bit Definition With Potential Protection Class for the 3GPP/GSM AMR 4,75 kbit/s Mode in 10 % Random Bit Errors

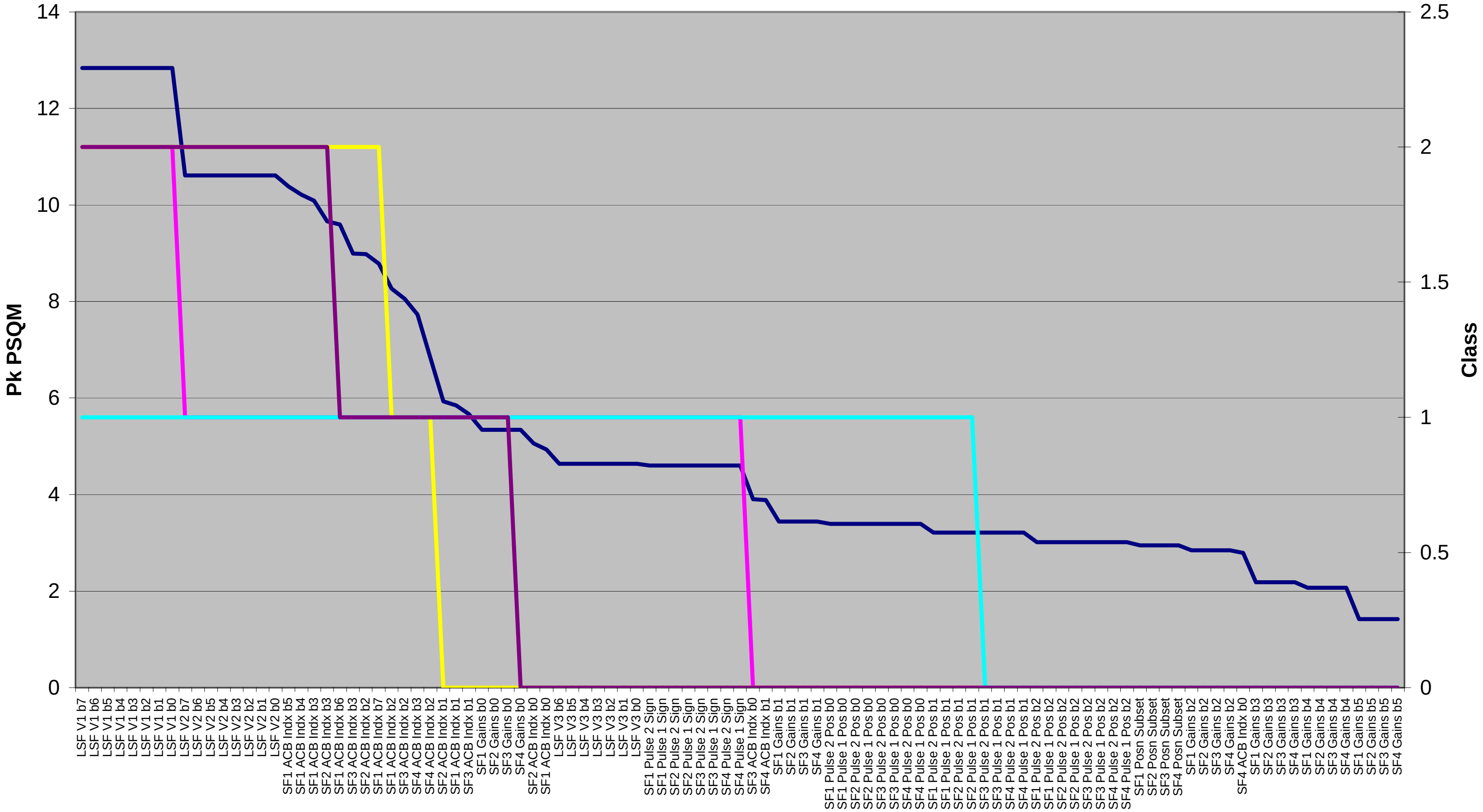

Figure 7.2: Ordered PeakPSQM and Bit Definition With Potential Protection Class for the 3GPP/GSM AMR 5,15 kbit/s Mode in 10 % Random Bit Errors

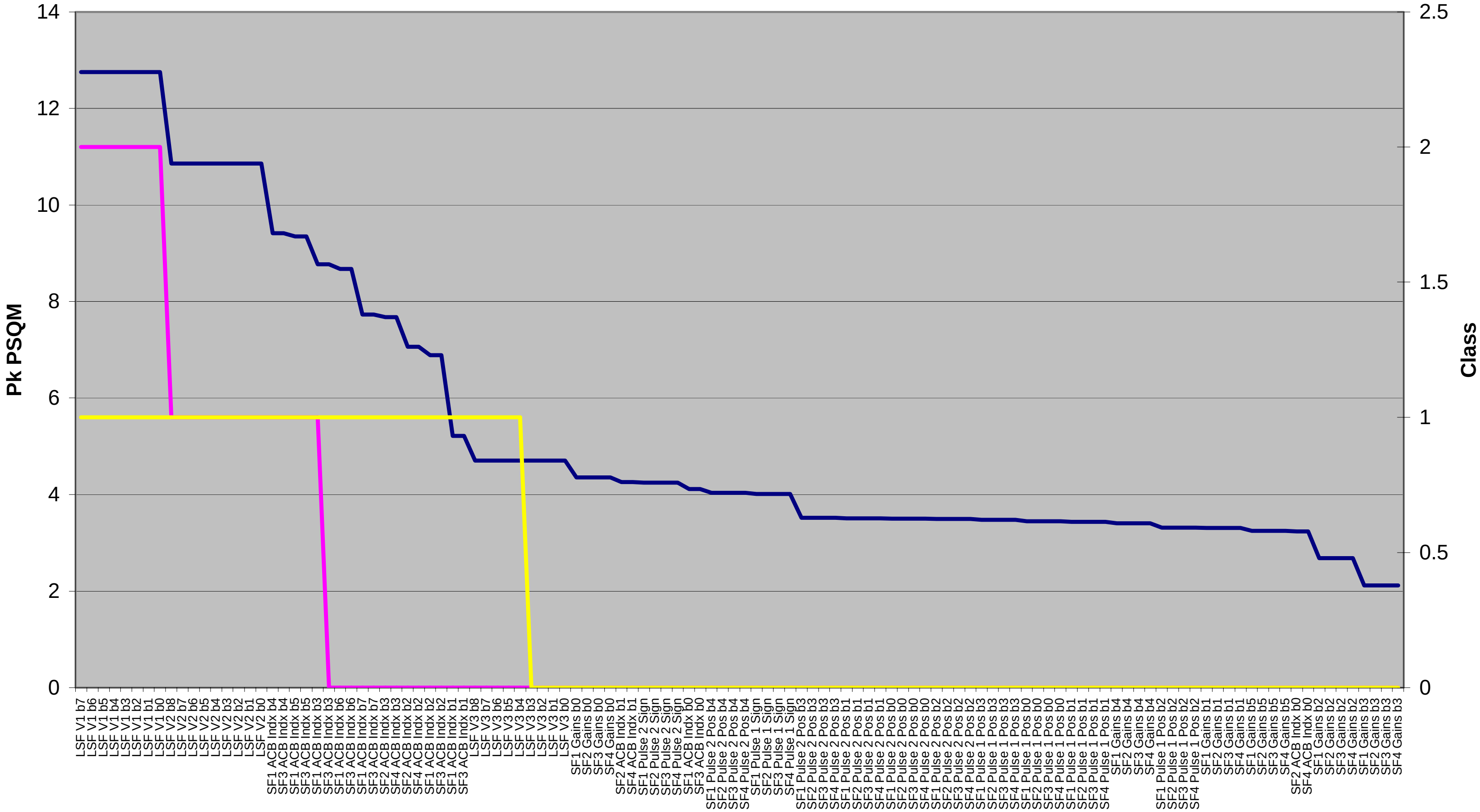

Figure 7.3: Ordered PeakPSQM and Bit Definition With Potential Protection Class for the 3GPP/GSM AMR 5,9 kbit/s Mode in 10 % Random Bit Errors

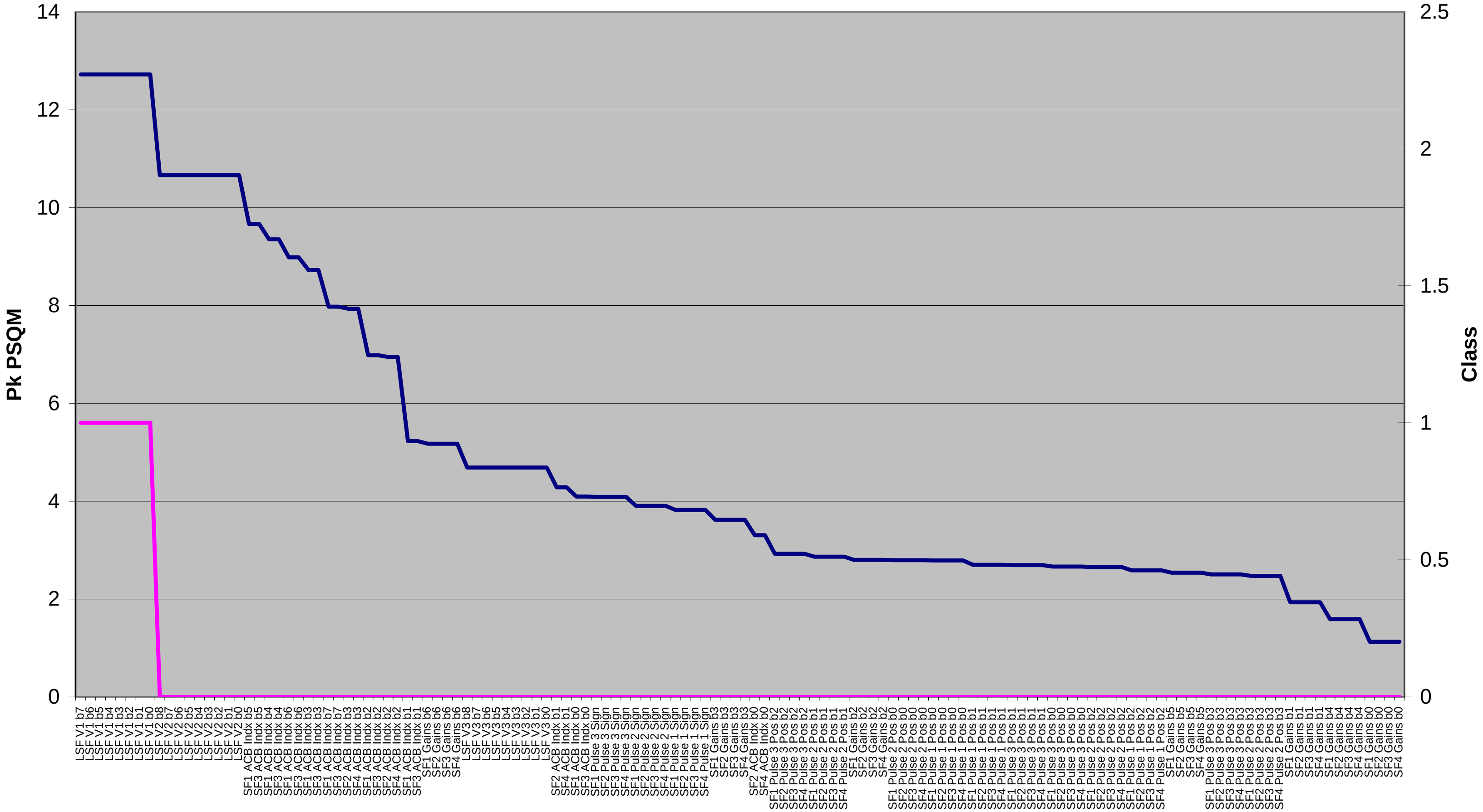

Figure 7.4: Ordered PeakPSQM and Bit Definition With Potential Protection Class for the 3GPP/GSM AMR 6,7 kbit/s Mode in 10 % Random Bit Errors

8 Coverage Performance of the FEC Schemes

According to four different channel conditions (Static, TU5, TU50 and HT200), and various C/I conditions, 'soft' channel errors were simulated using a TETRA MODEM and channel simulation package and applied to the FEC encoded data streams prior to FEC decoding and speech was synthesized. Each synthesized speech file was compared using ITU-T Recommendation P.861 [1] to the appropriate error-free speech and both the PSQM and Peak-PSQM values obtained. The FEC options, identified in clause 7, for each 3GPP/GSM AMR Mode were compared.

8.1 4,75 kbit/s Mode

The results for the four options of FEC for the 4,75 kbit/s mode are shown in figures 8.1 to 8.8. Figures 8.1 and 8.2 are applicable to the static channel, figures 8.3 and 8.4 are applicable to the TU5 channel, figures 8.5 and 8.6 are applicable to the TU50 channel and figures 8.7 and 8.8 are applicable to the HT200 channel.

When compared to the performance of the TETRA speech codec, it is clear that there is a trade-off between performance according to the PSQM and the Peak PSQM metrics. Of the four possible FEC options, the method which appears to provide performance most similar to that of the TETRA codec is Option 3.

Figures 8.1 and 8.2 appear to show the PSQM decreasing with C/I for very poor channels. This effect appears to results from the muting of frames during severe channel conditions and is not significant.

The TU5 channel clearly appears to vary too slowly for meaningful statistics of the Peak PSQM measure to be obtained.

8.2 5,15 kbit/s Mode

The results for the four options of FEC for the 5,15 kbit/s mode are shown in figures 8.9 to 8.16.

As for the 4,75 kbit/s mode, there is a clear trade-off between performance according to the PSQM and the Peak PSQM metrics. Of the four possible FEC options, the method which appears to provide the best balance of performance is Option 3.

As for the 4,75 kbit/s mode, figures 8.9 and 8.10 appear to show the PSQM decreasing with C/I for very poor channels. Again, the TU5 channel clearly appears to vary too slowly for meaningful statistics of the Peak PSQM measure to be obtained.

8.3 5,9 kbit/s Mode

The results for the two options of FEC for the 5,9 kbit/s mode are shown in figures 8.17 to 8.24.

The trade-off between PSQM and the Peak PSQM metric performance is again clear. Of the FEC options considered, the method which appears to provide the best balance of performance is Option 2.

8.4 6,7 kbit/s Mode

The results for the FEC of the 6,7 kbit/s mode are shown in figures 8.25 to 8.32.

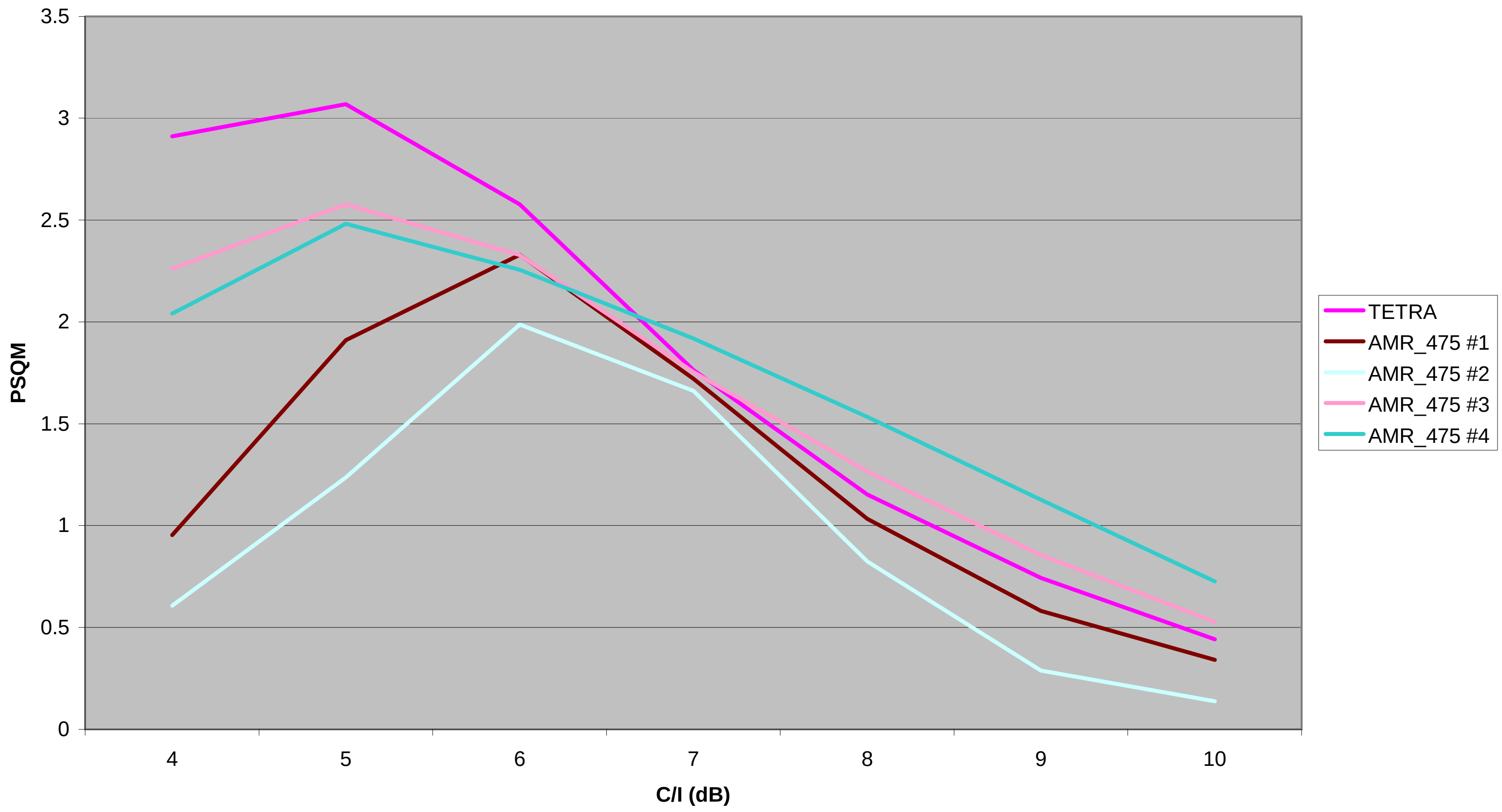

Figure 8.1: Performance of the 3GPP/GSM AMR 4,75 kbit/s Mode for the Static Channel in Terms of PSQM

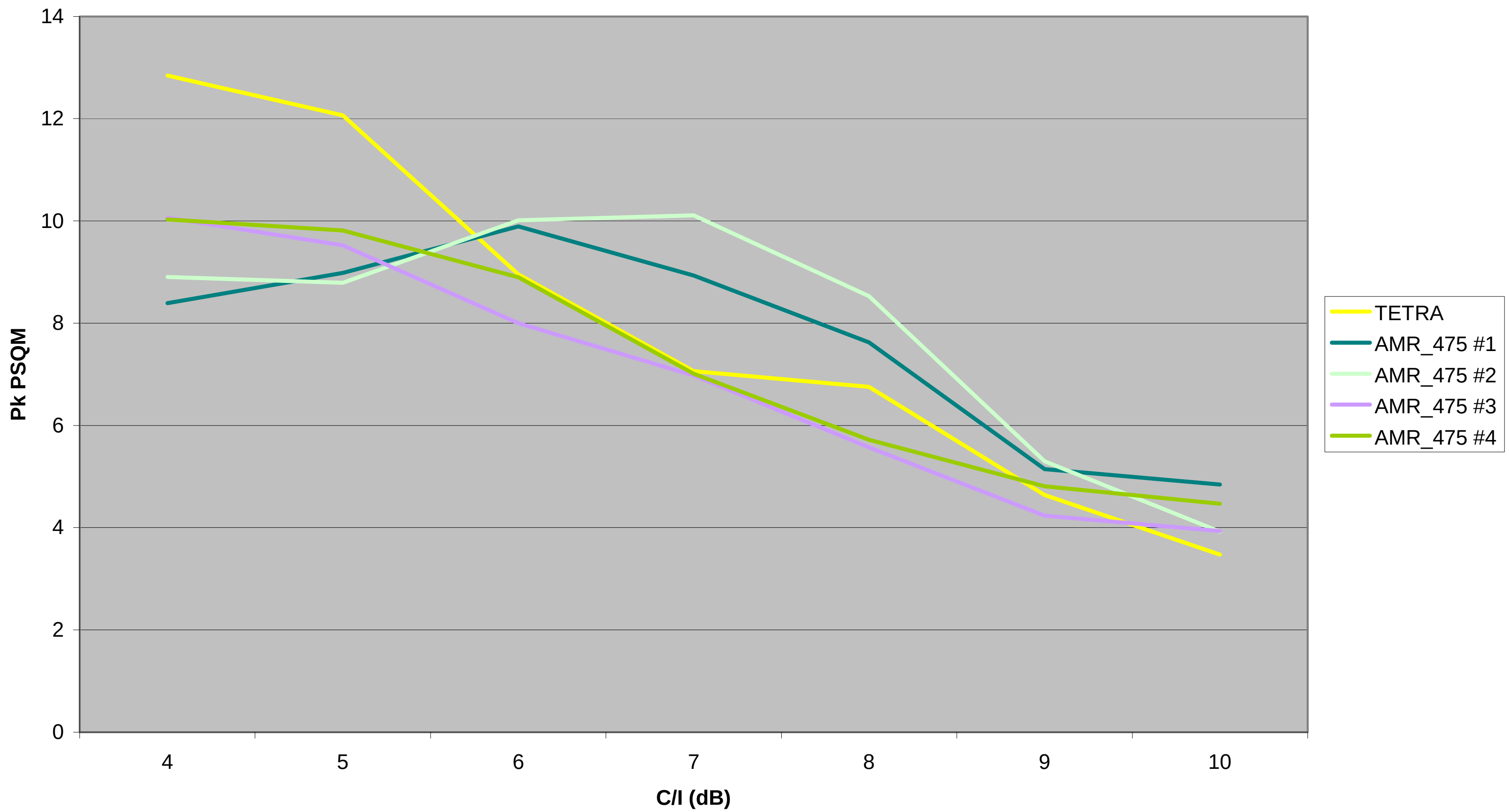

Figure 8.2: Performance of the 3GPP/GSM AMR 4,75 kbit/s Mode for the Static Channel in Terms of Peak PSQM

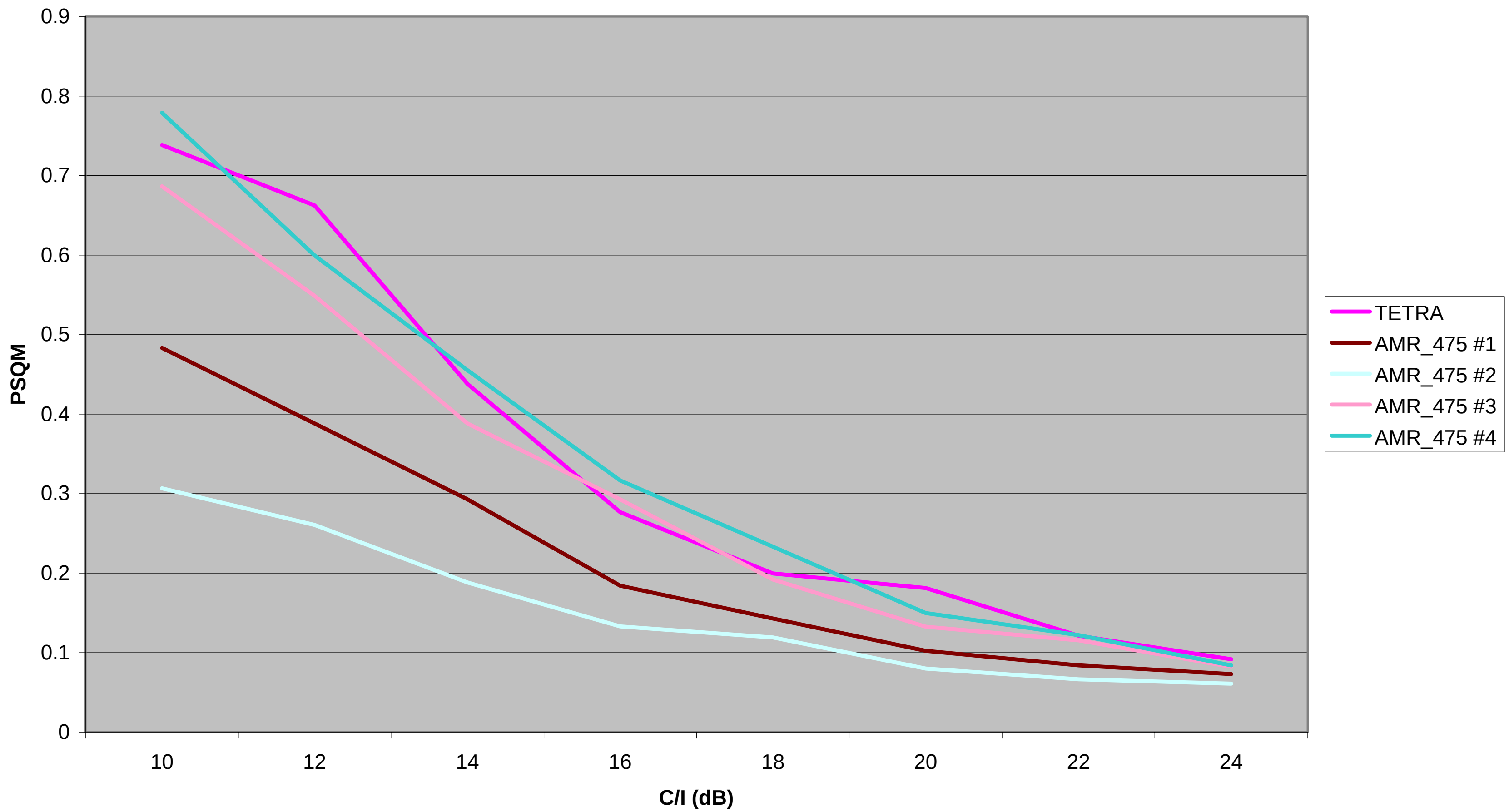

Figure 8.3: Performance of the 3GPP/GSM AMR 4,75 kbit/s Mode for the TU5 Channel in Terms of PSQM

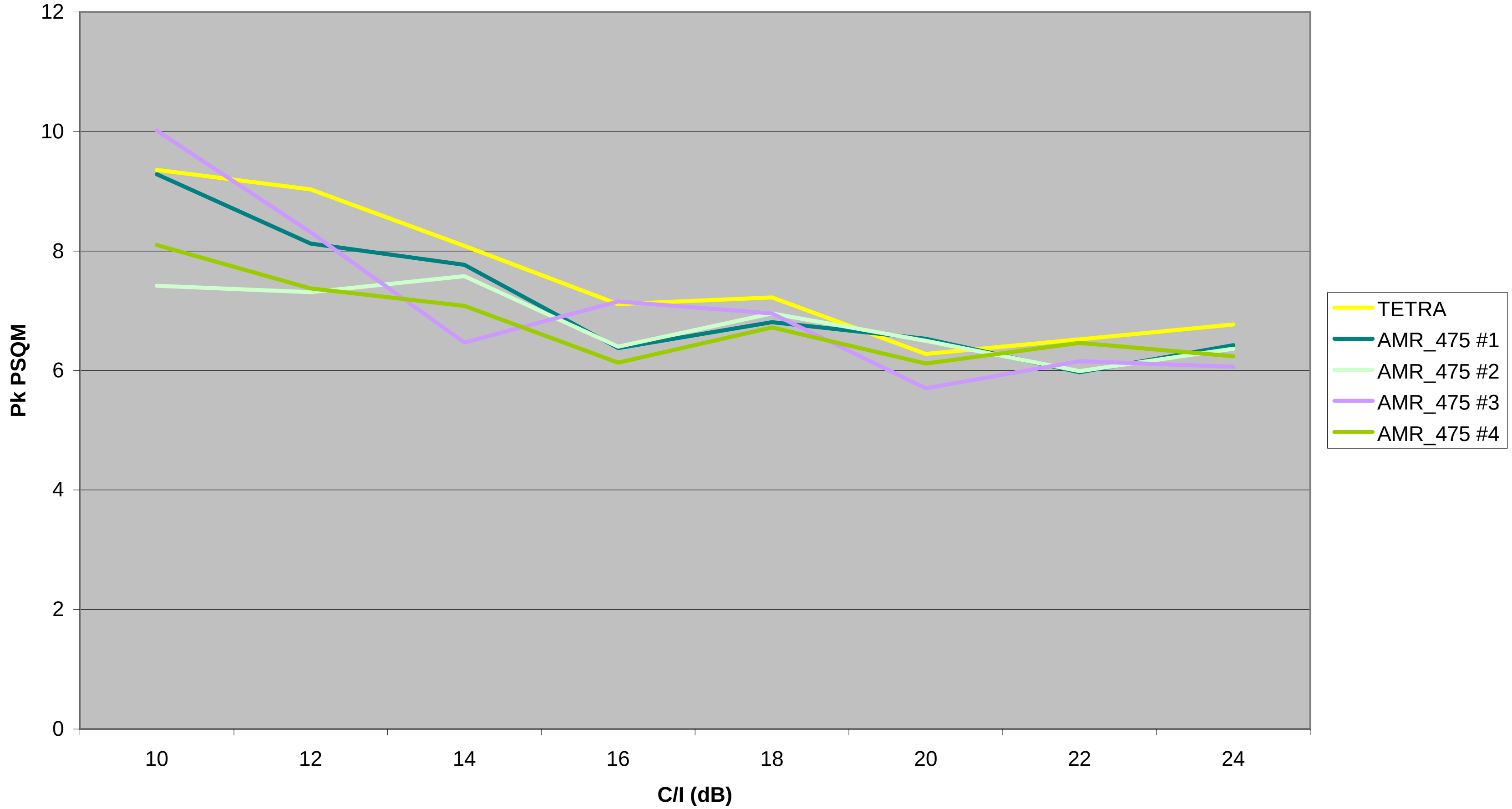

Figure 8.4: Performance of the 3GPP/GSM AMR 4,75 kbit/s Mode for the TU5 Channel in Terms of Peak PSQM

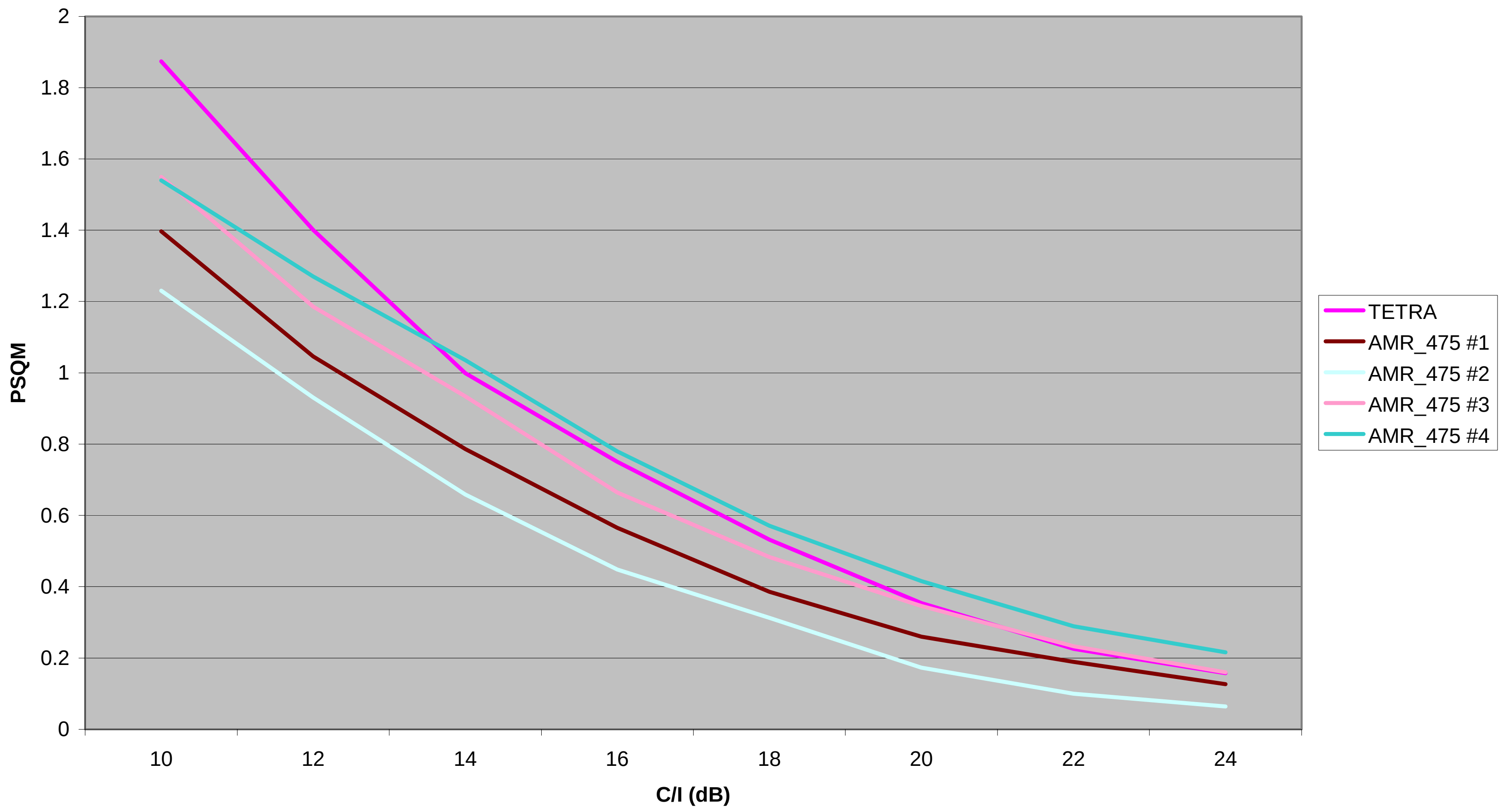

Figure 8.5: Performance of the 3GPP/GSM AMR 4,75 kbit/s Mode for the TU50 Channel in Terms of PSQM

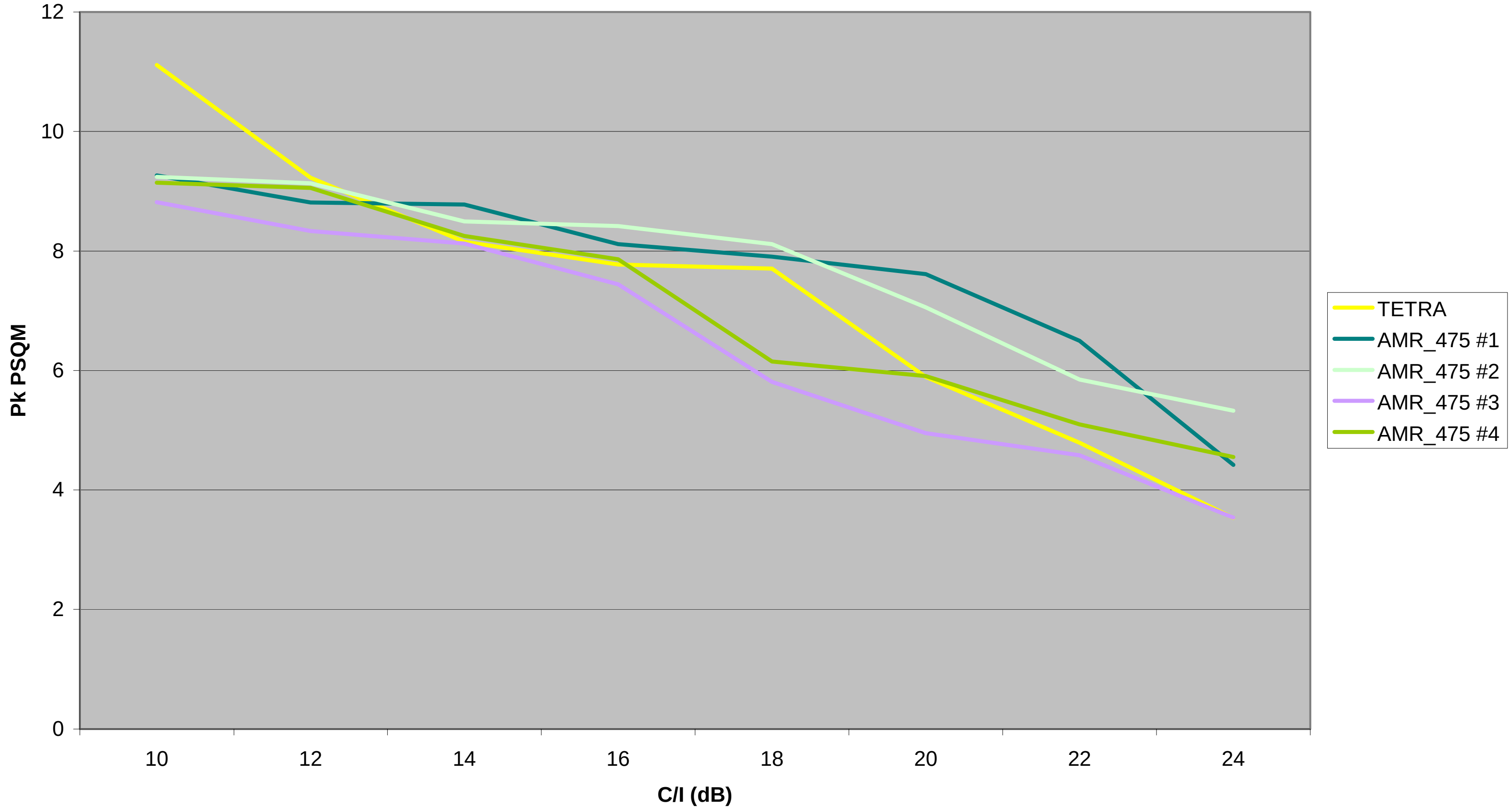

Figure 8.6: Performance of the 3GPP/GSM AMR 4,75 kbit/s Mode for the TU50 Channel in Terms of Peak PSQM

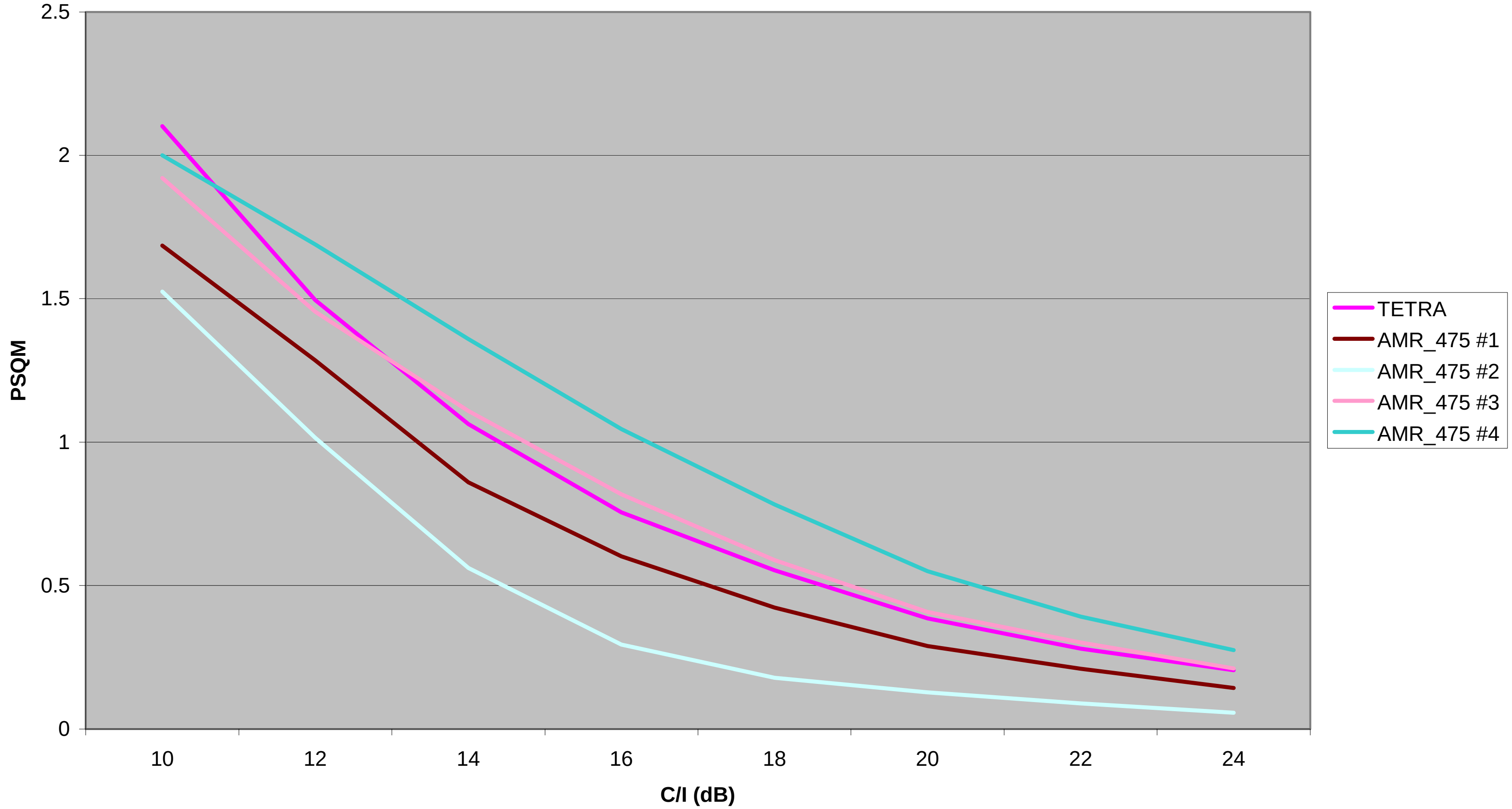

Figure 8.7: Performance of the 3GPP/GSM AMR 4,75 kbit/s Mode for the HT200 Channel in Terms of PSQM

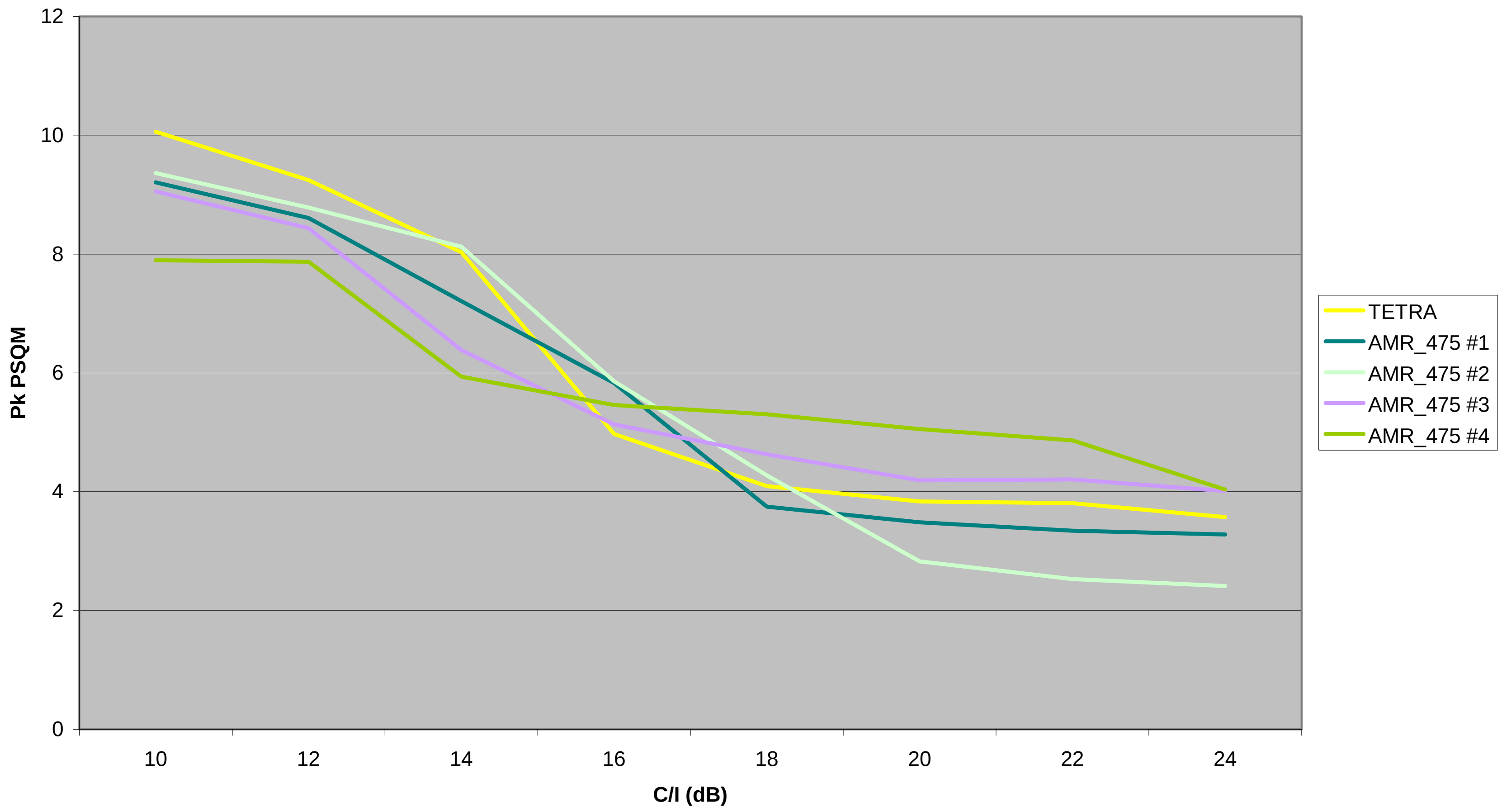

Figure 8.8: Performance of the 3GPP/GSM AMR 4,75 kbit/s Mode for the HT200 Channel in Terms of Peak PSQM

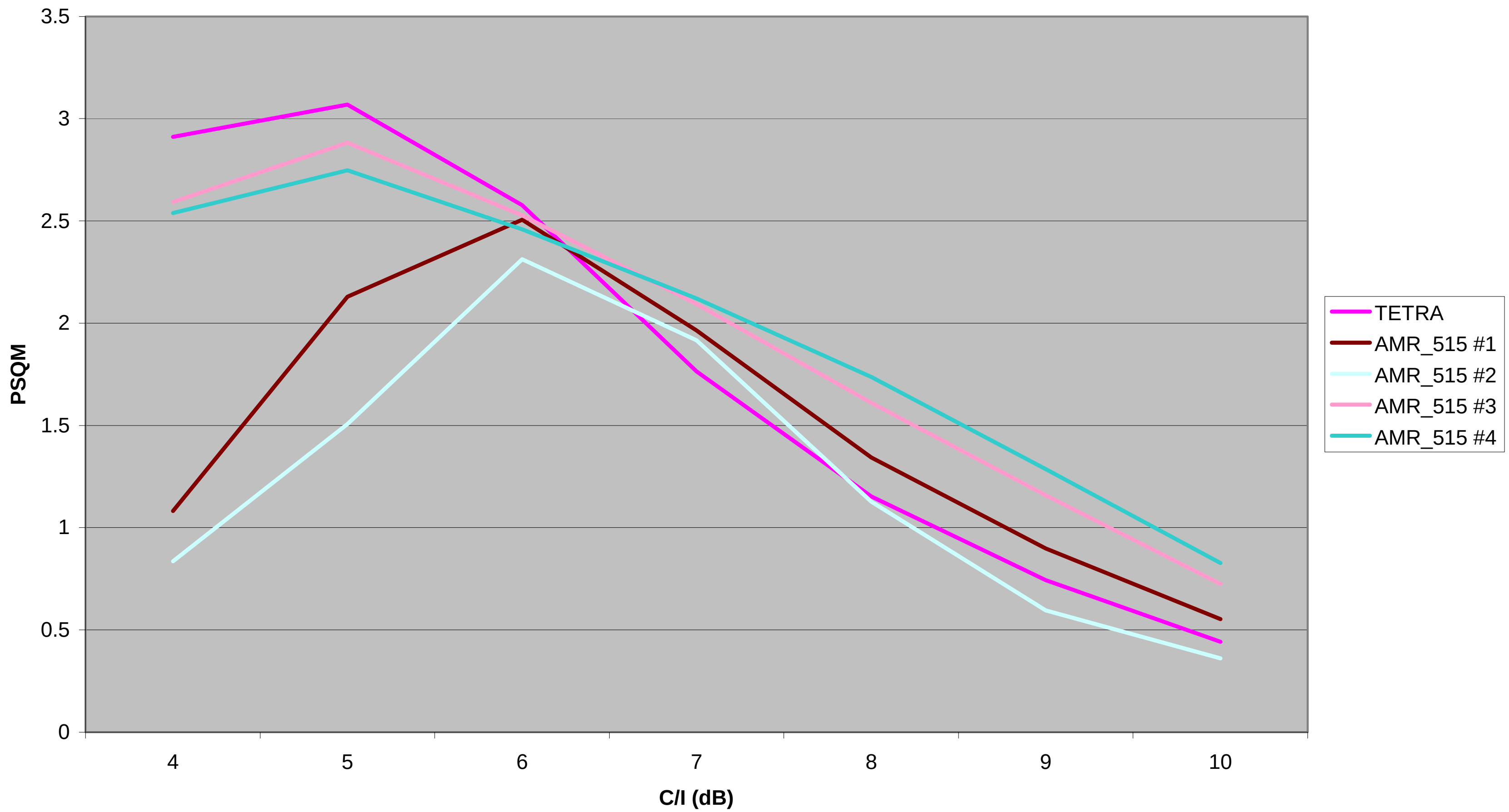

Figure 8.9: Performance of the 3GPP/GSM AMR 5,15 kbit/s Mode for the Static Channel in Terms of PSQM

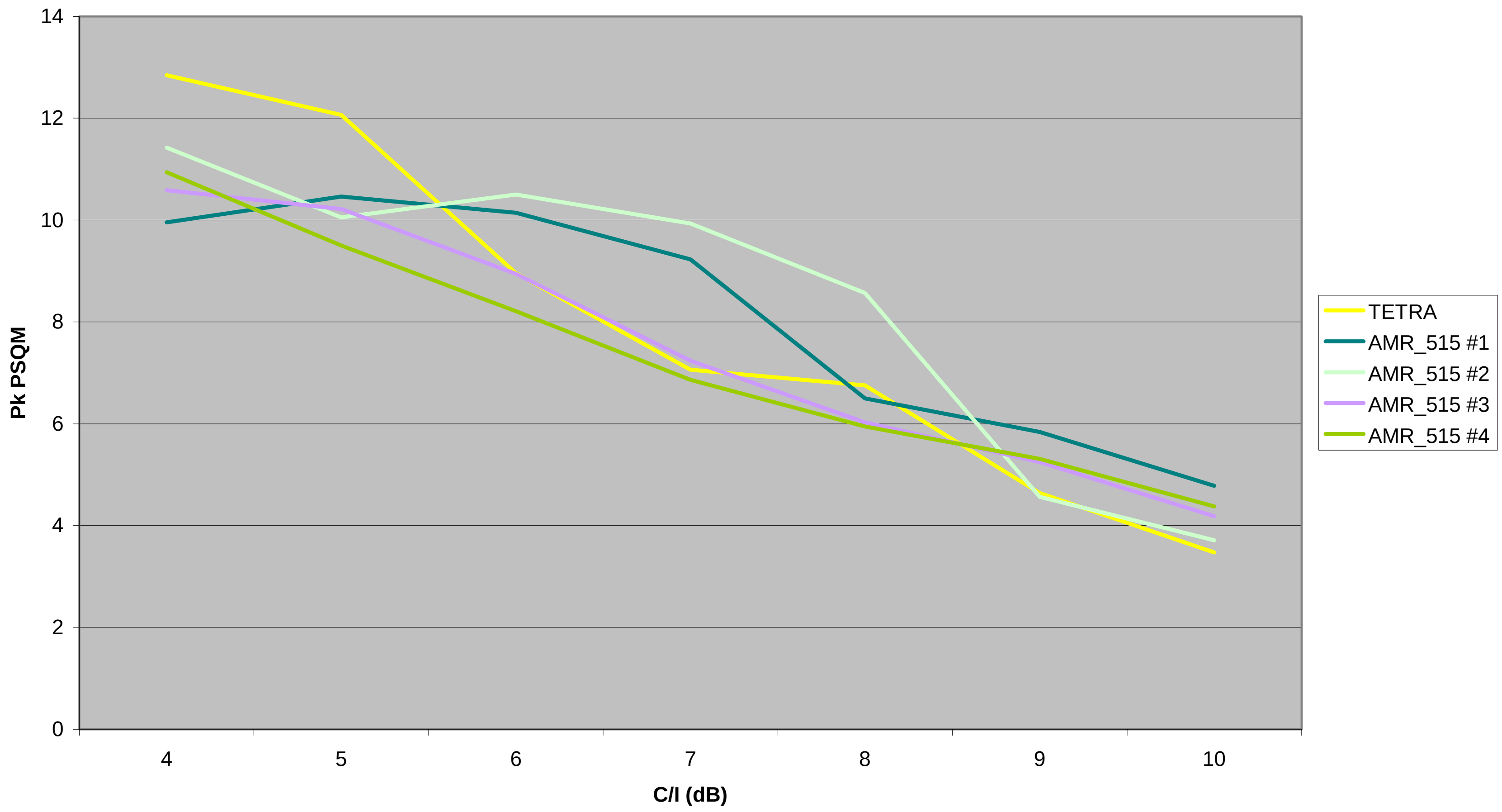

Figure 8.10: Performance of the 3GPP/GSM AMR 5,15 kbit/s Mode for the Static Channel in Terms of Peak PSQM

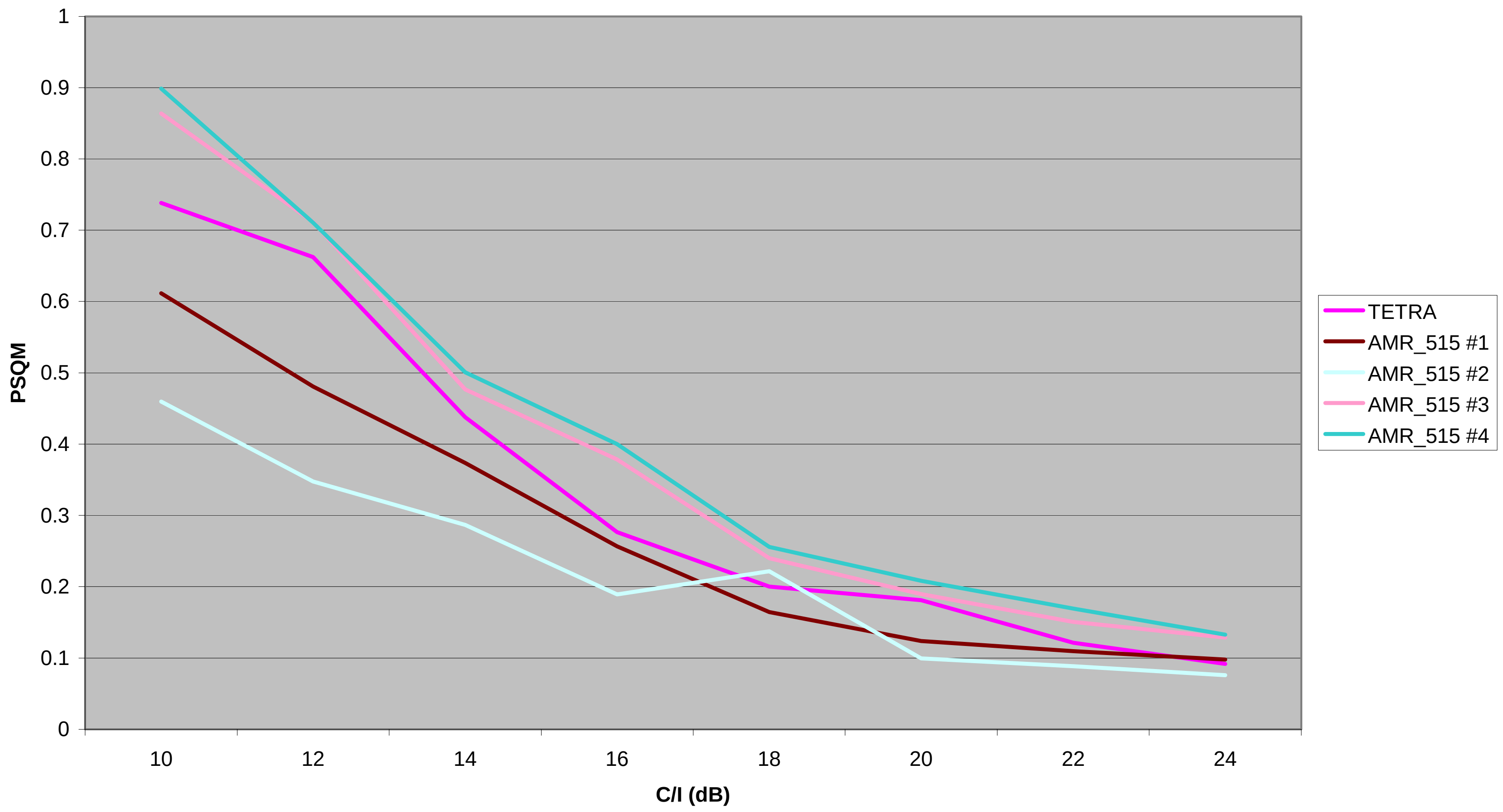

Figure 8.11: Performance of the 3GPP/GSM AMR 5,15 kbit/s Mode for the TU5 Channel in Terms of PSQM

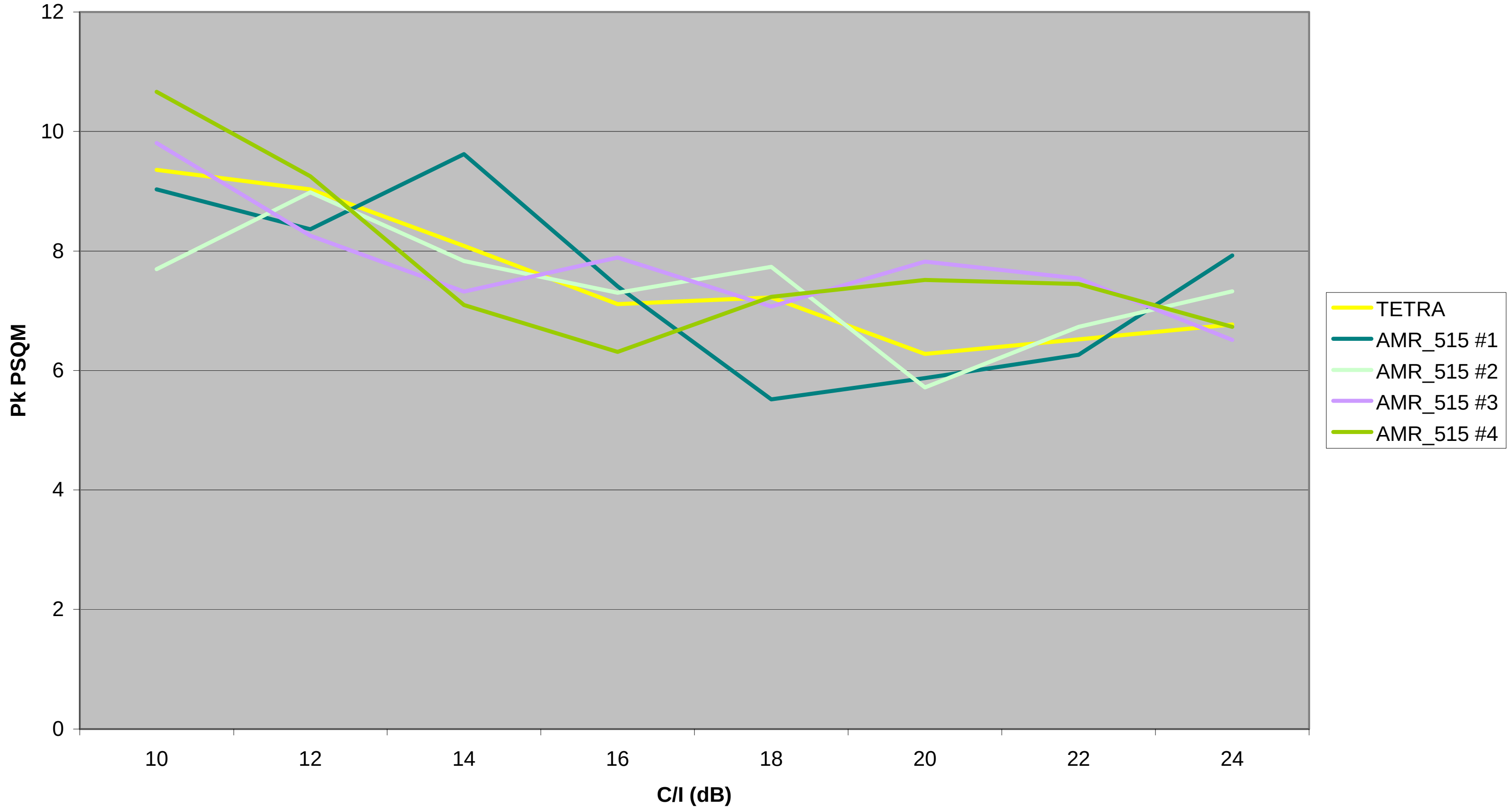

Figure 8.12: Performance of the 3GPP/GSM AMR 5,15 kbit/s Mode for the TU5 Channel in Terms of Peak PSQM

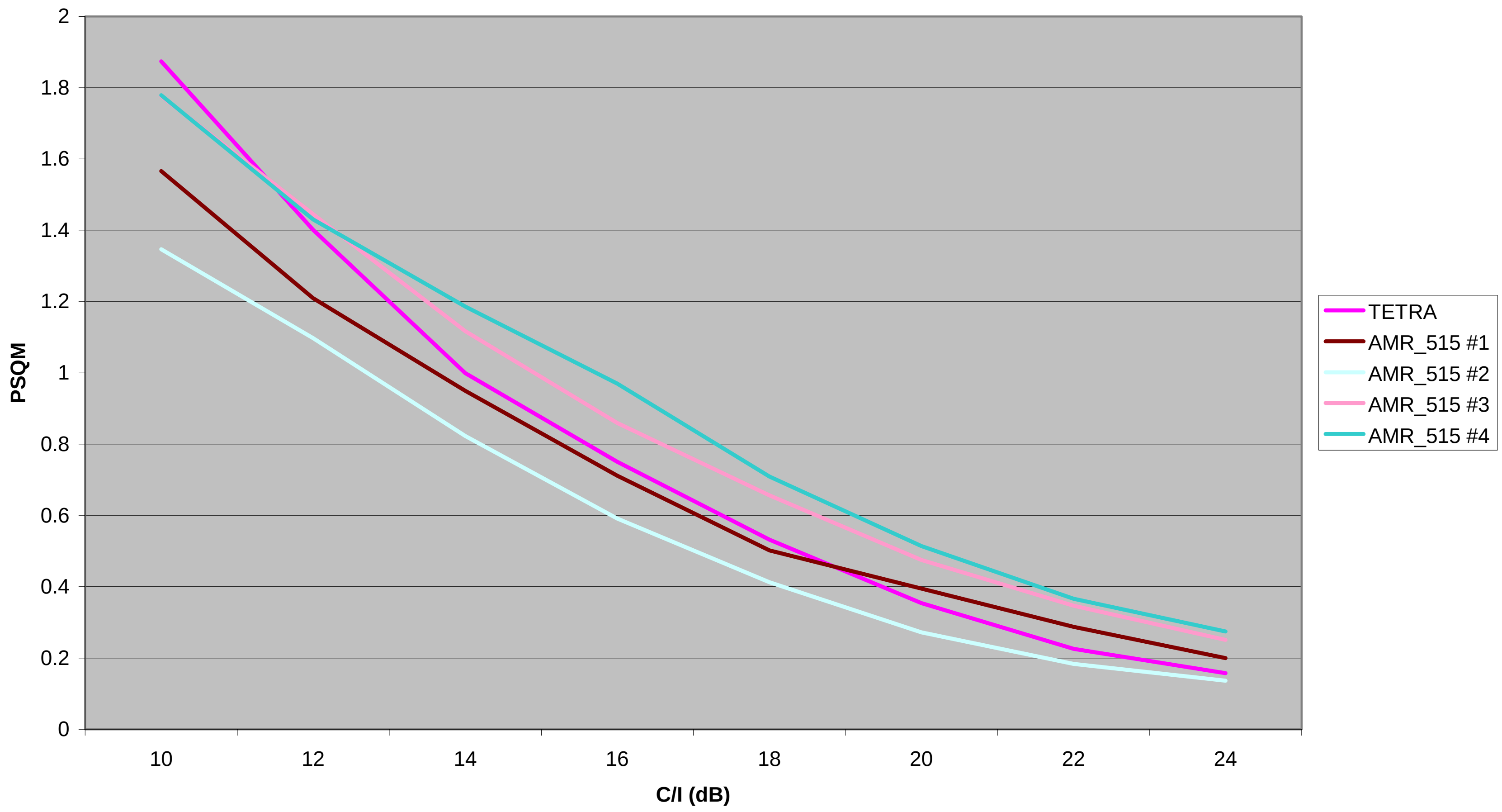

Figure 8.13: Performance of the 3GPP/GSM AMR 5,15 kbit/s Mode for the TU50 Channel in Terms of PSQM

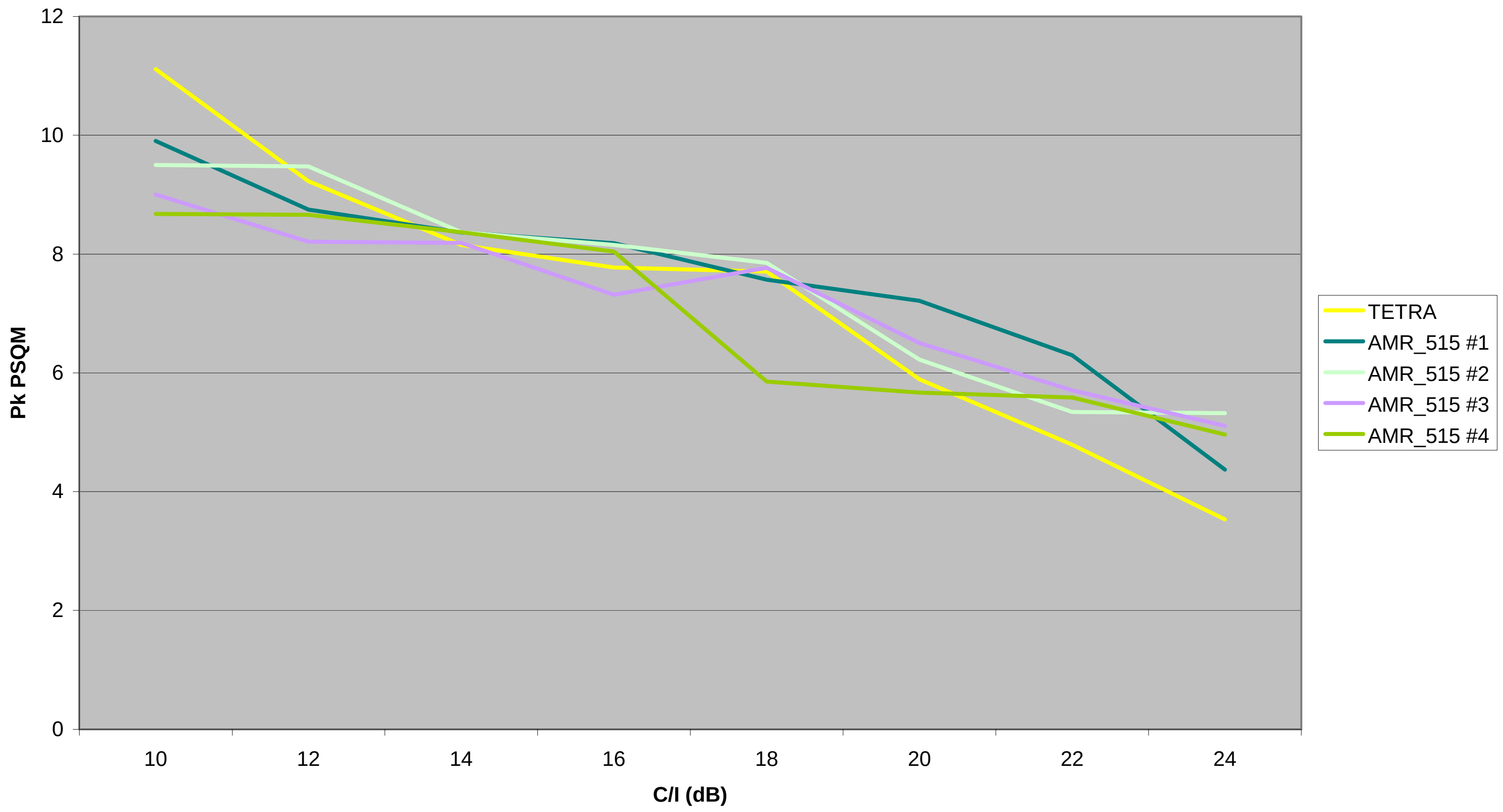

Figure 8.14: Performance of the 3GPP/GSM AMR 5,15 kbit/s Mode for the TU50 Channel in Terms of Peak PSQM

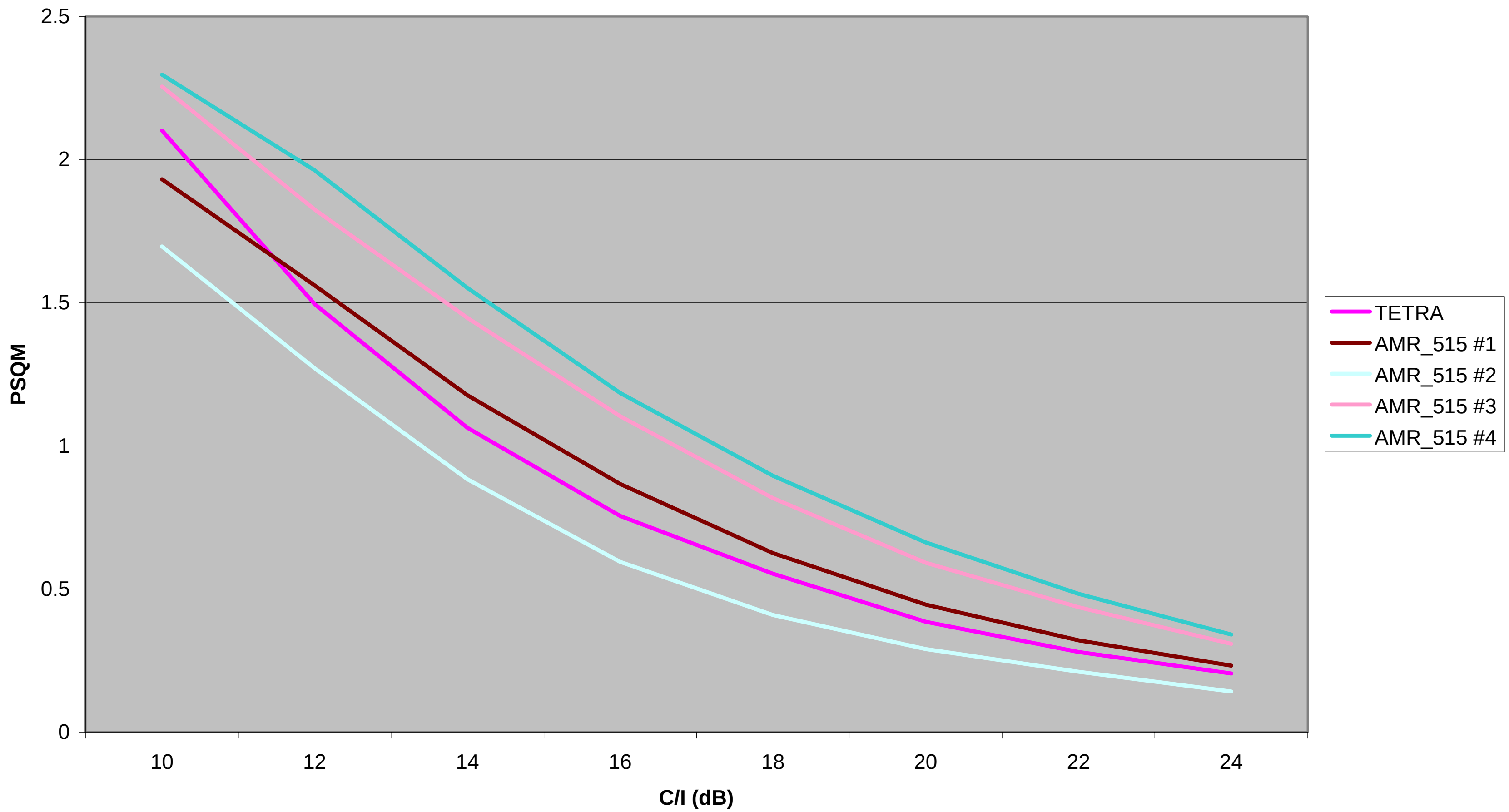

Figure 8.15: Performance of the 3GPP/GSM AMR 5,15 kbit/s Mode for the HT200 Channel in Terms of PSQM

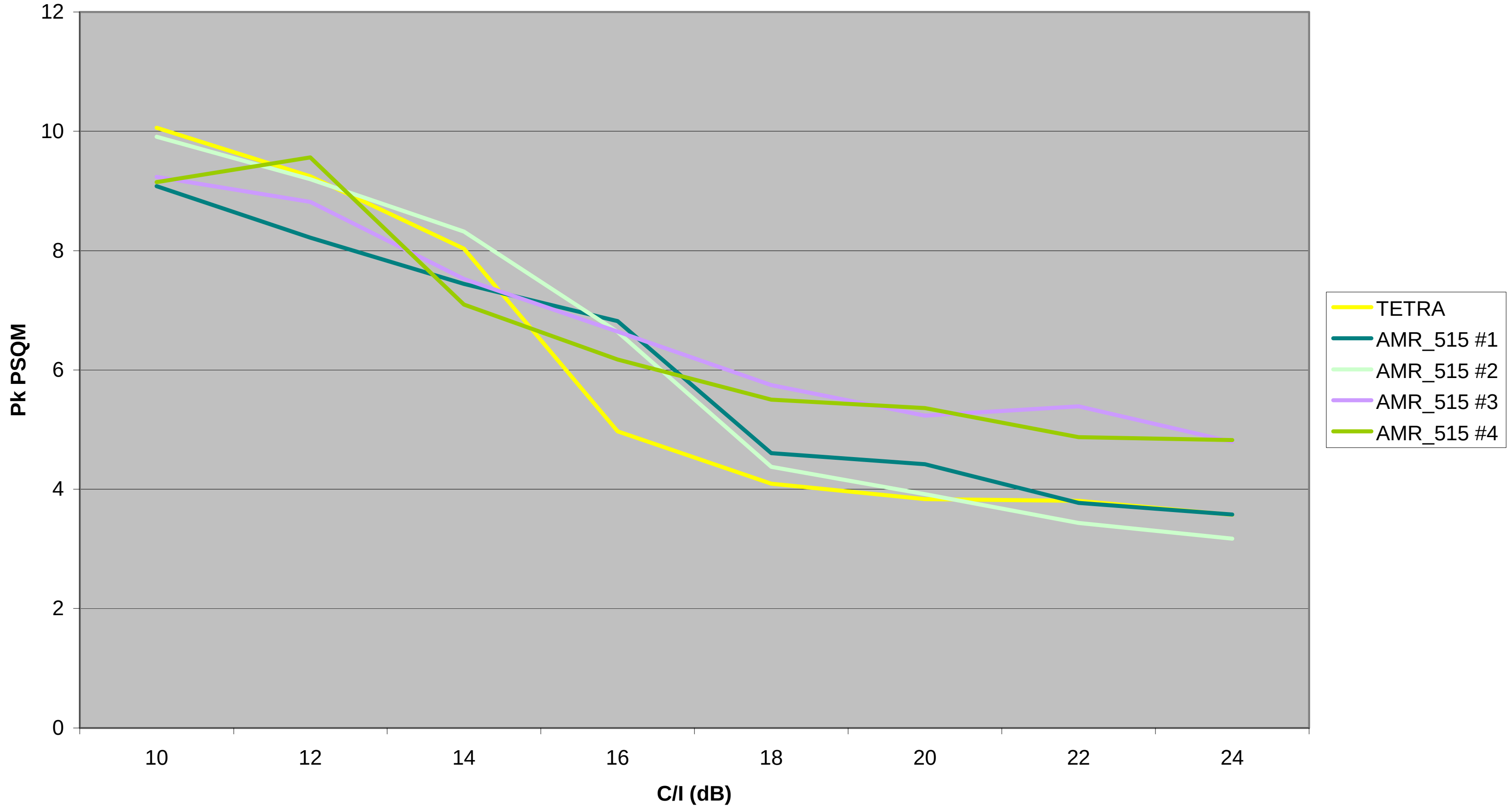

Figure 8.16: Performance of the 3GPP/GSM AMR 5,15 kbit/s Mode for the HT200 Channel in Terms of Peak PSQM

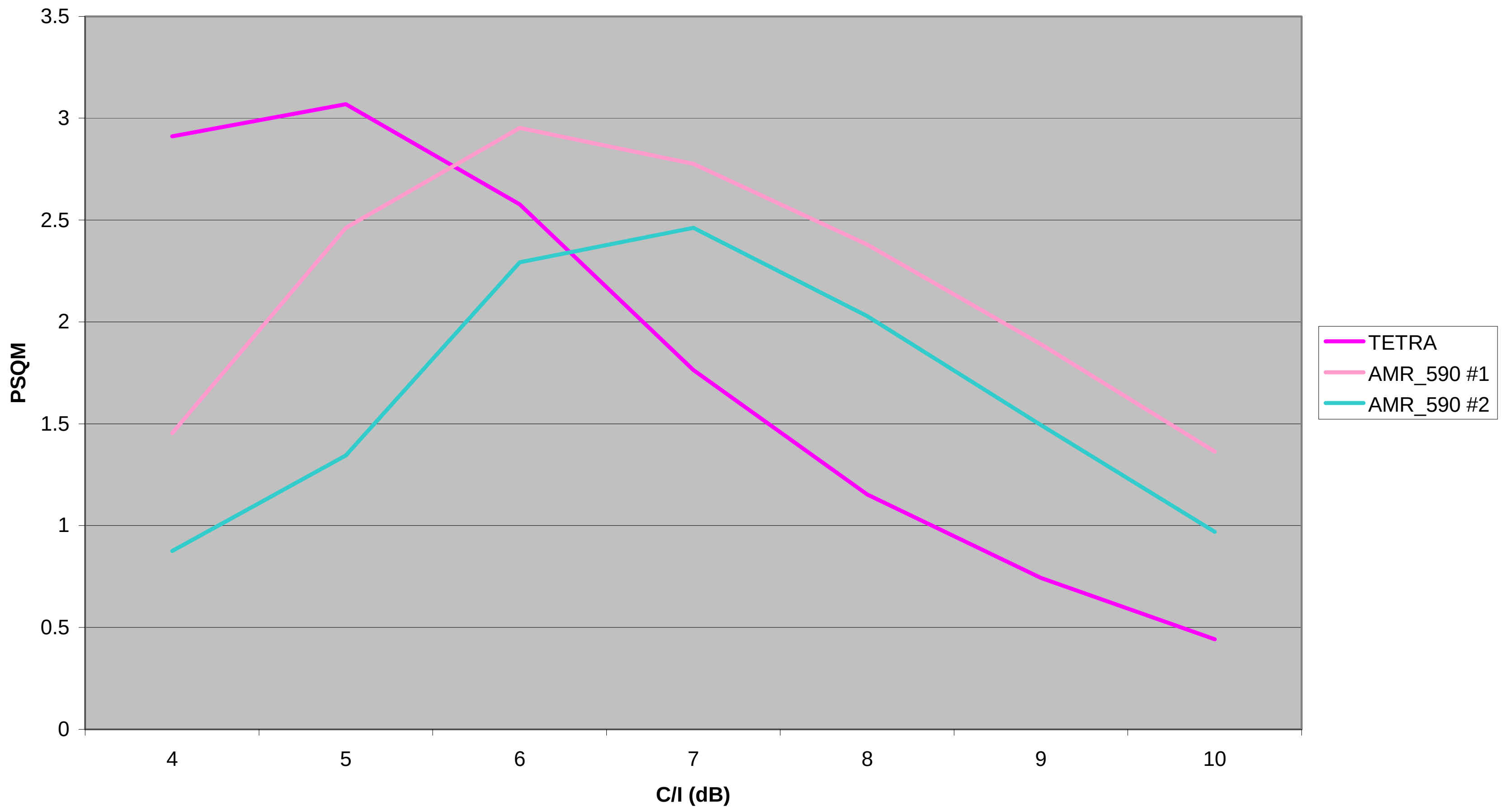

Figure 8.17: Performance of the 3GPP/GSM AMR 5,9 kbit/s Mode for the Static Channel in Terms of PSQM

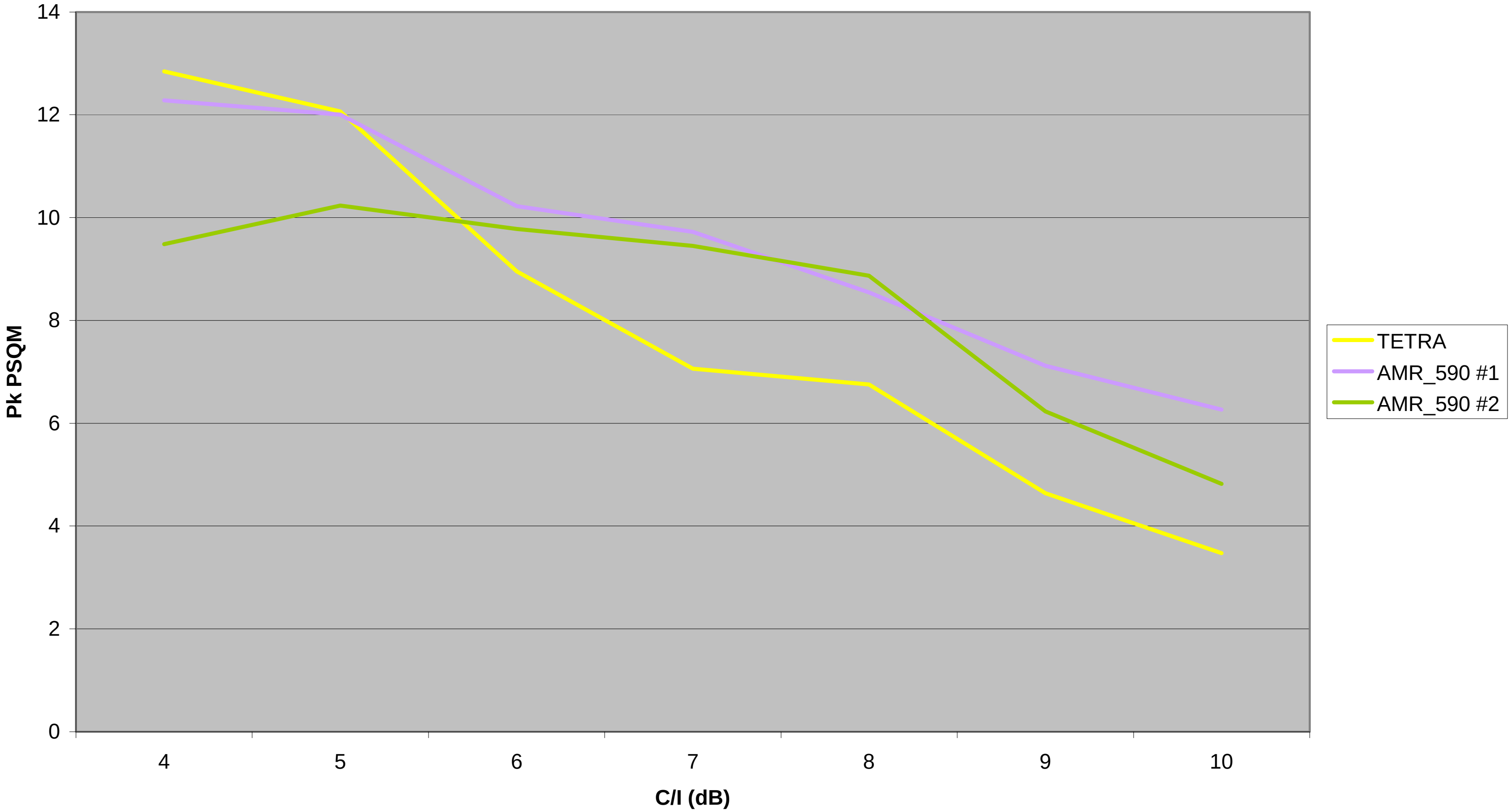

Figure 8.18: Performance of the 3GPP/GSM AMR 5,9 kbit/s Mode for the Static Channel in Terms of Peak PSQM

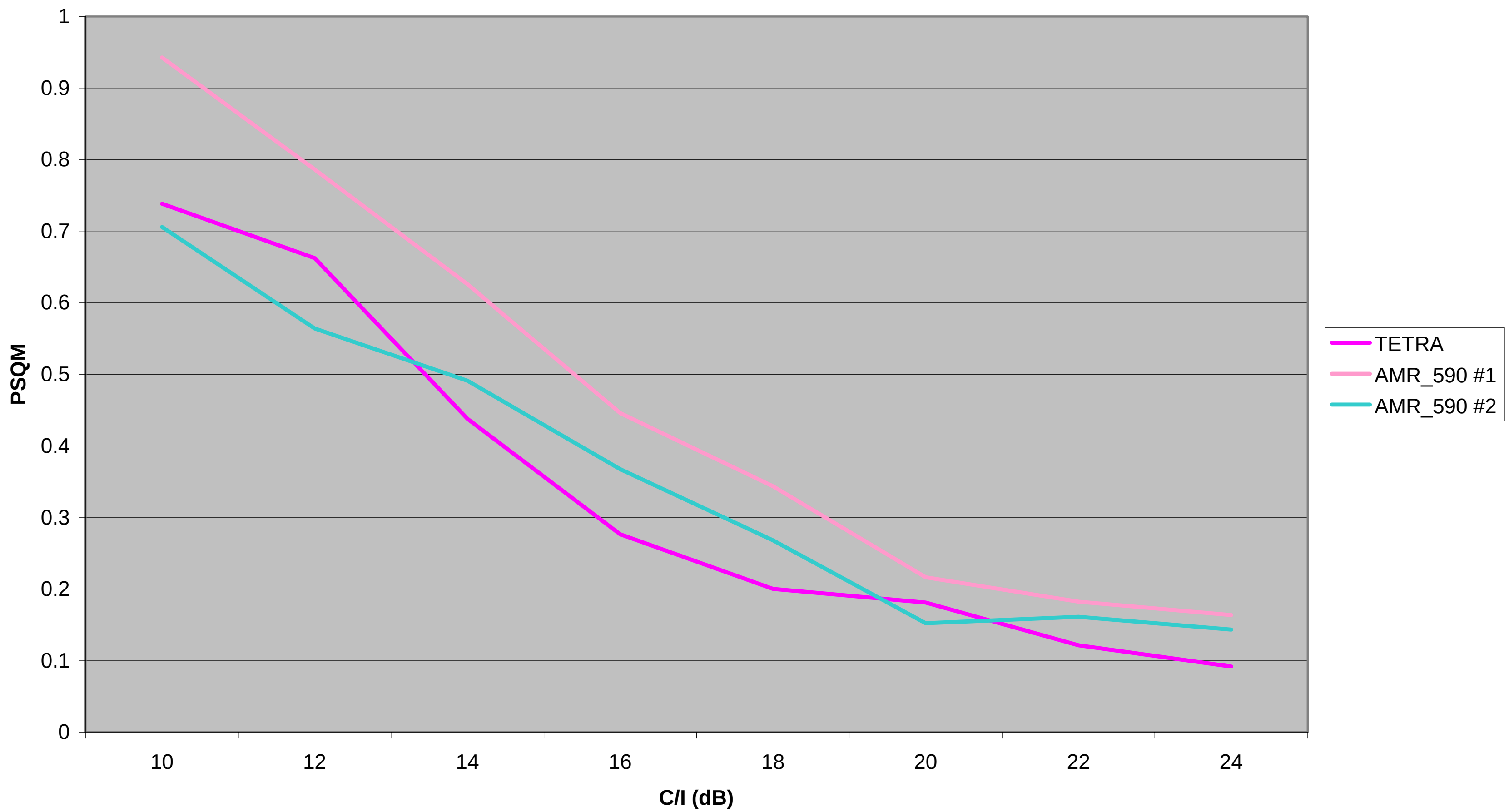

Figure 8.19: Performance of the 3GPP/GSM AMR 5,9 kbit/s Mode for the TU5 Channel in Terms of PSQM

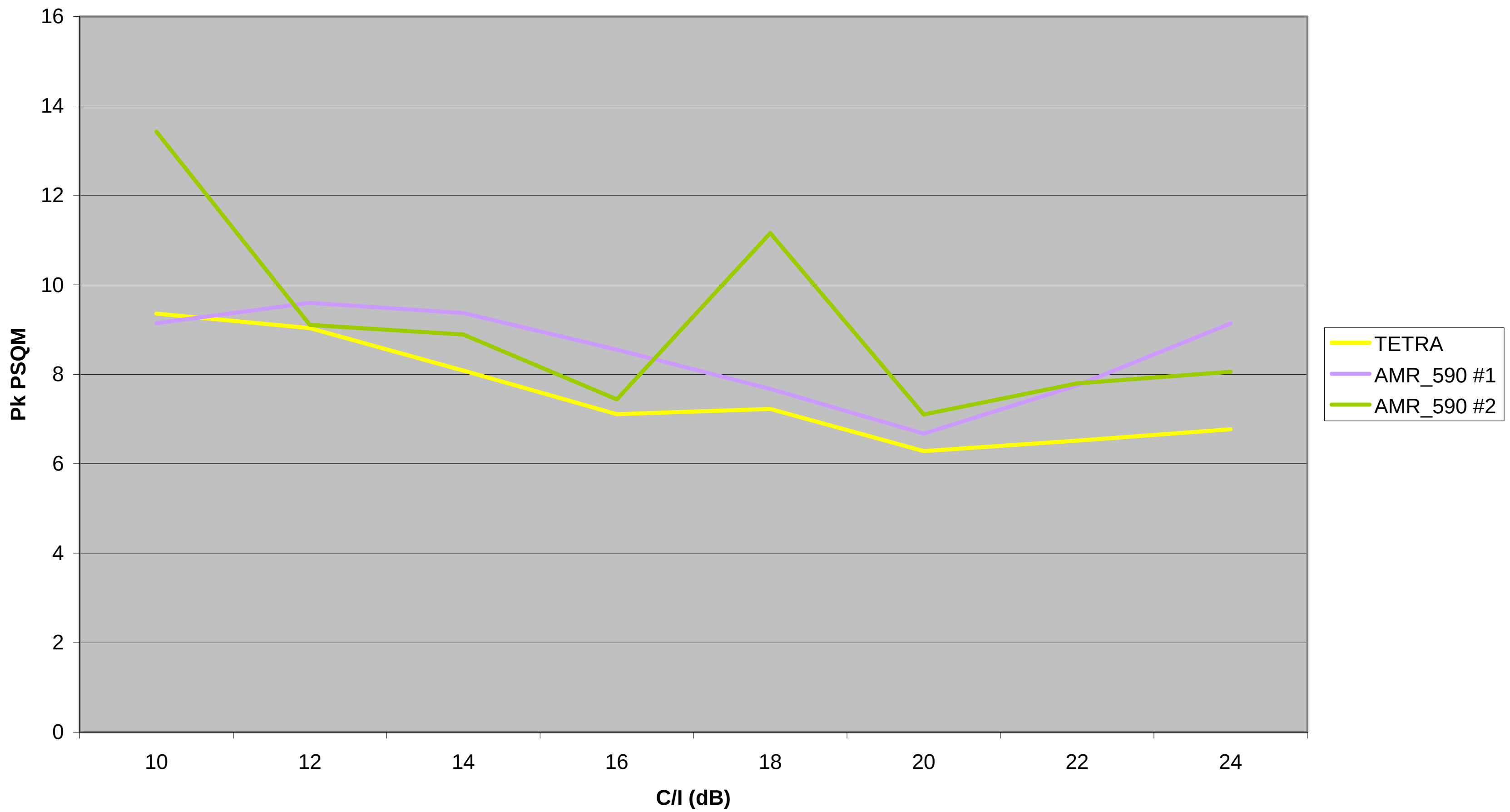

Figure 8.20: Performance of the 3GPP/GSM AMR 5,9 kbit/s Mode for the TU5 Channel in Terms of Peak PSQM

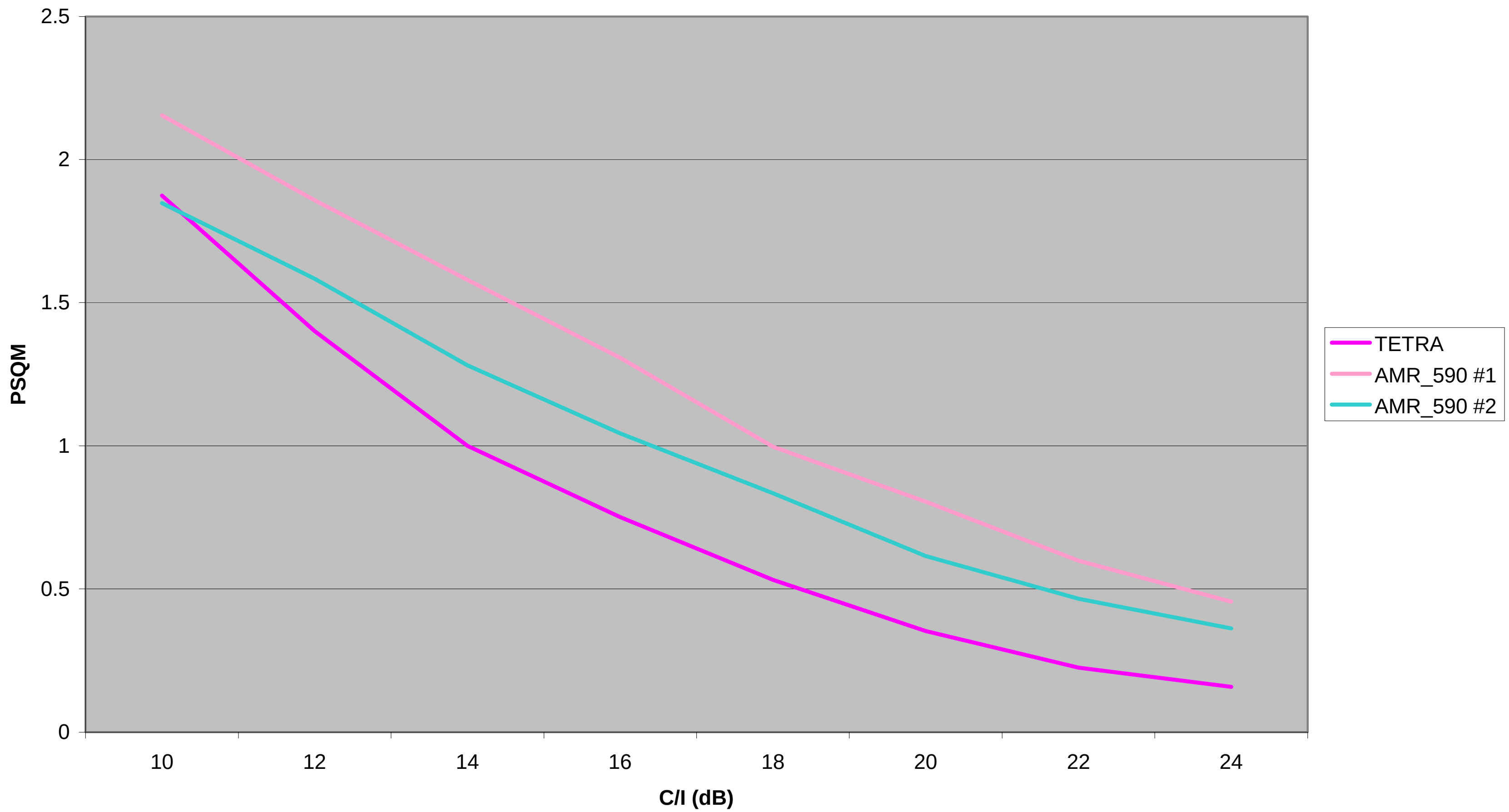

Figure 8.21: Performance of the 3GPP/GSM AMR 5,9 kbit/s Mode for the TU50 Channel in Terms of PSQM

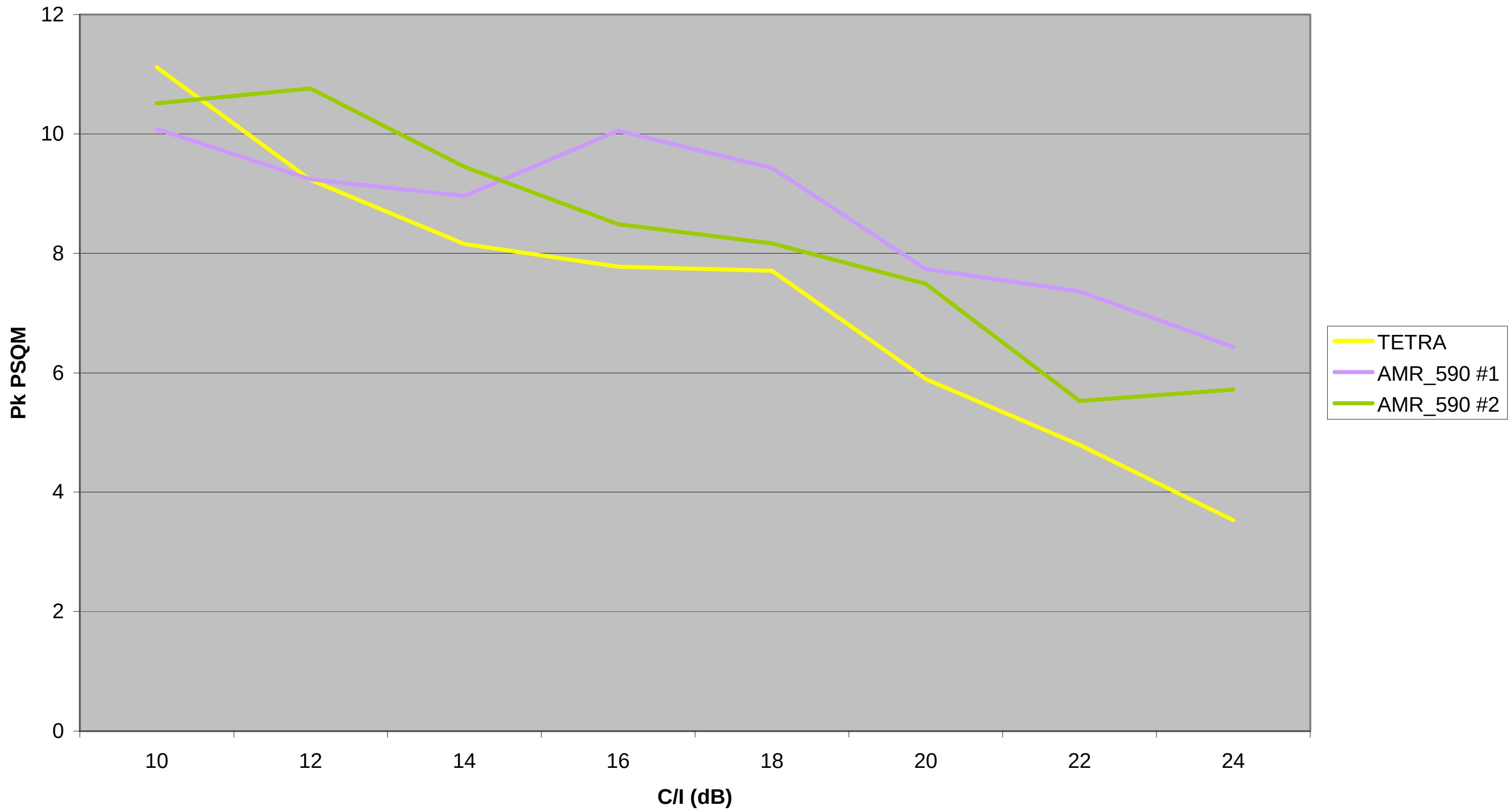

Figure 8.22: Performance of the 3GPP/GSM AMR 5,9 kbit/s Mode for the TU50 Channel in Terms of Peak PSQM

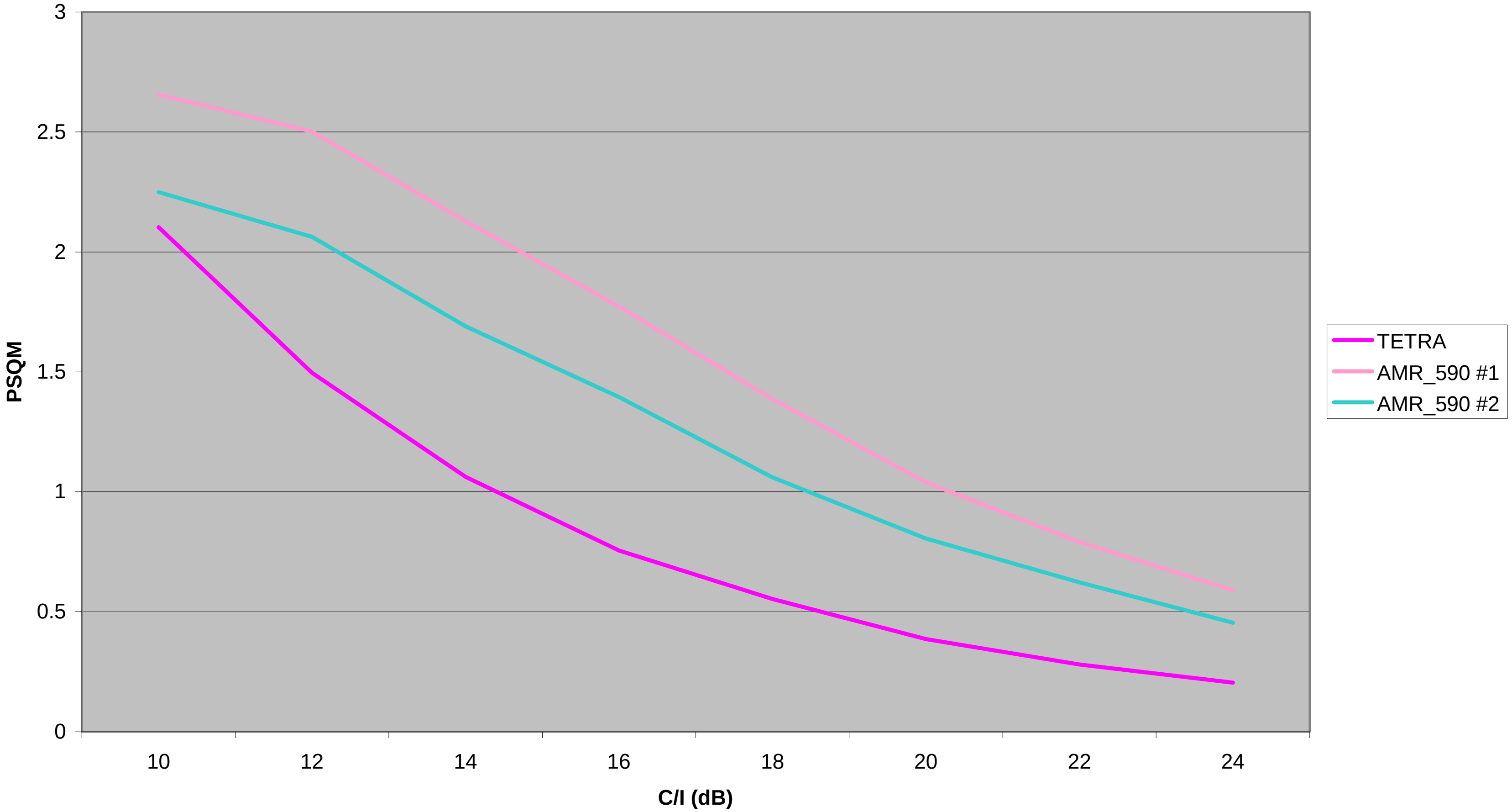

Figure 8.23: Performance of the 3GPP/GSM AMR 5,9 kbit/s Mode for the HT200 Channel in Terms of PSQM

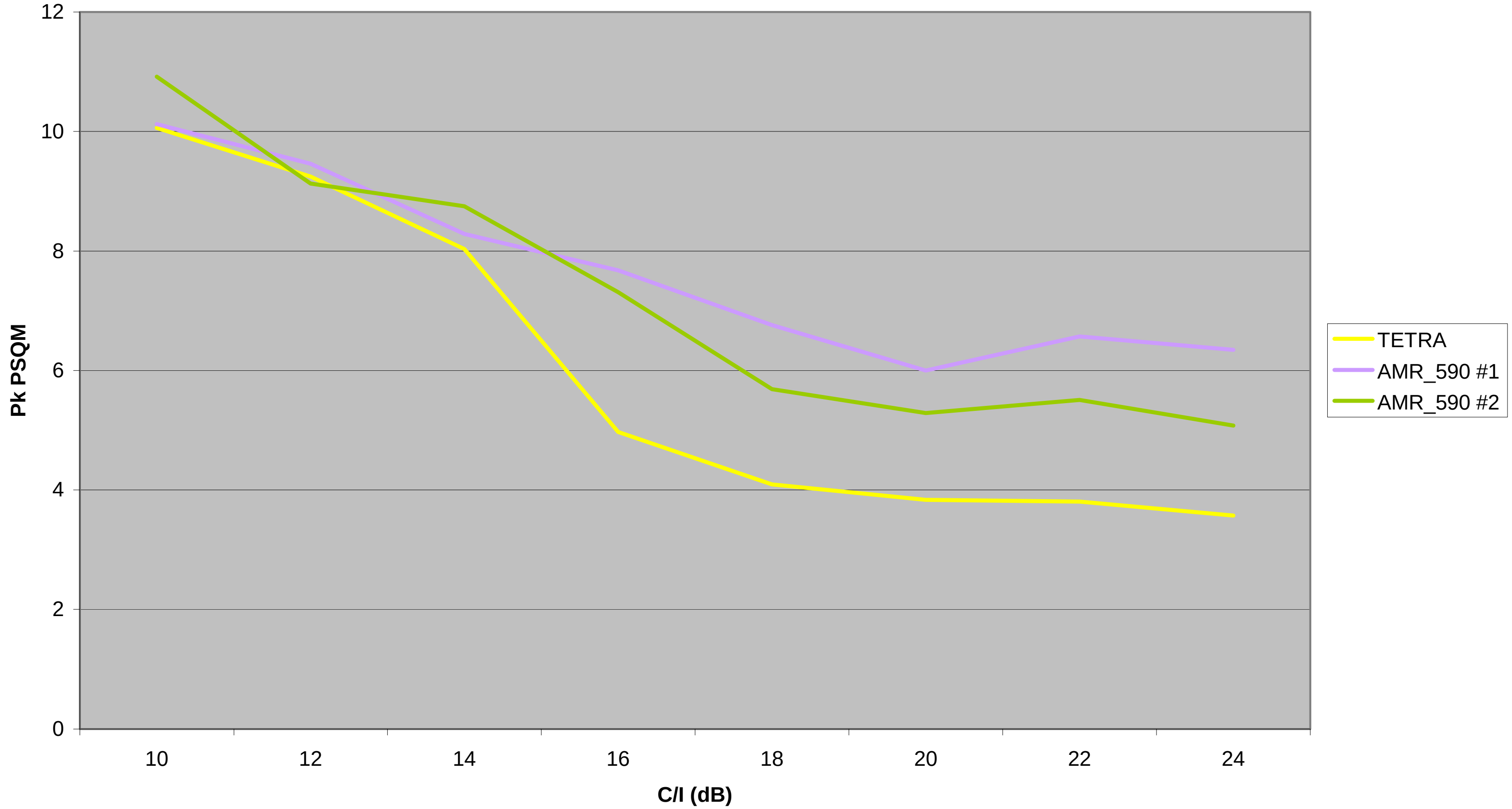

Figure 8.24: Performance of the 3GPP/GSM AMR 5,9 kbit/s Mode for the HT200 Channel in Terms of Peak PSQM

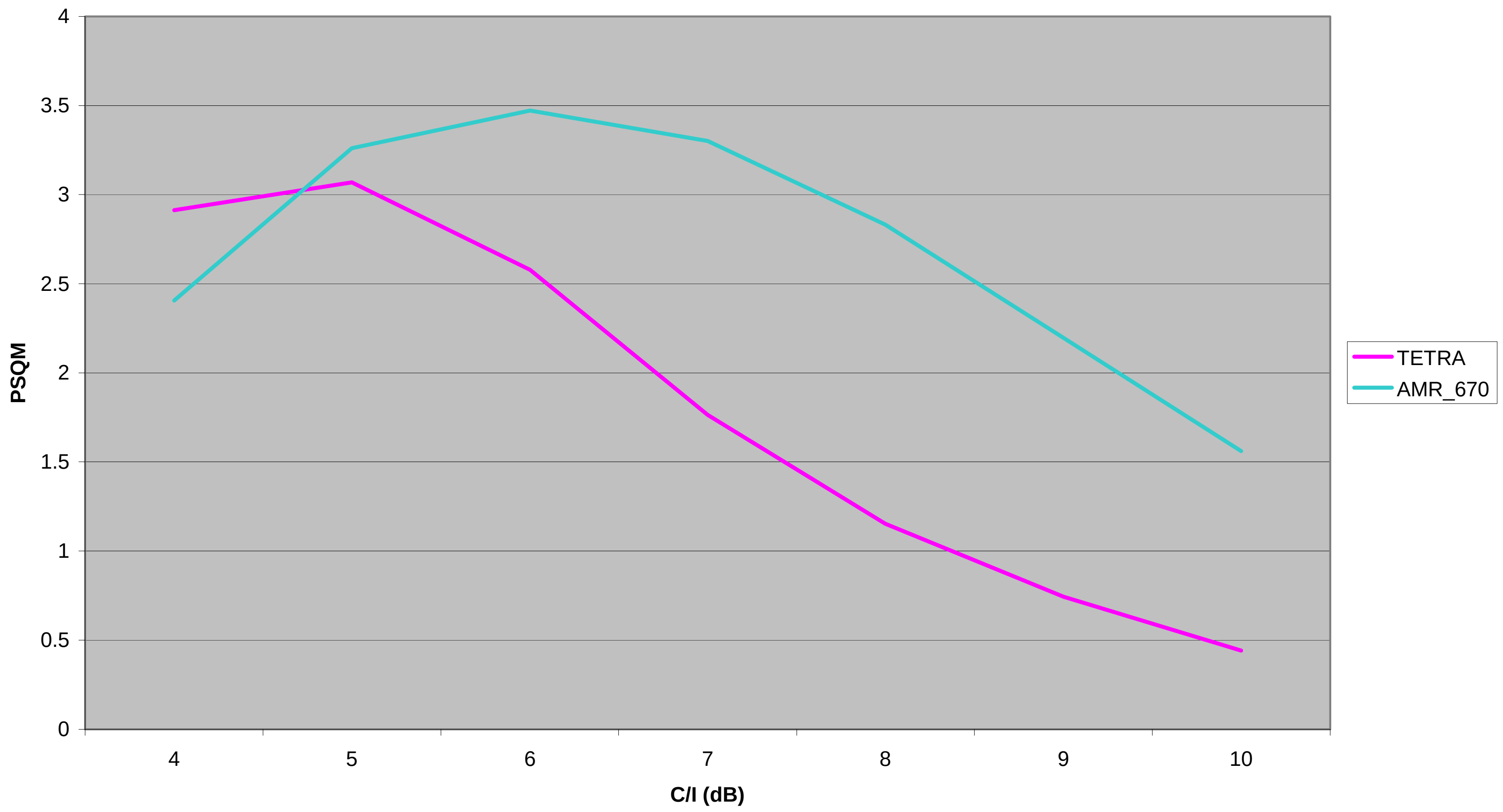

Figure 8.25: Performance of the 3GPP/GSM AMR 6,7 kbit/s Mode for the Static Channel in Terms of PSQM

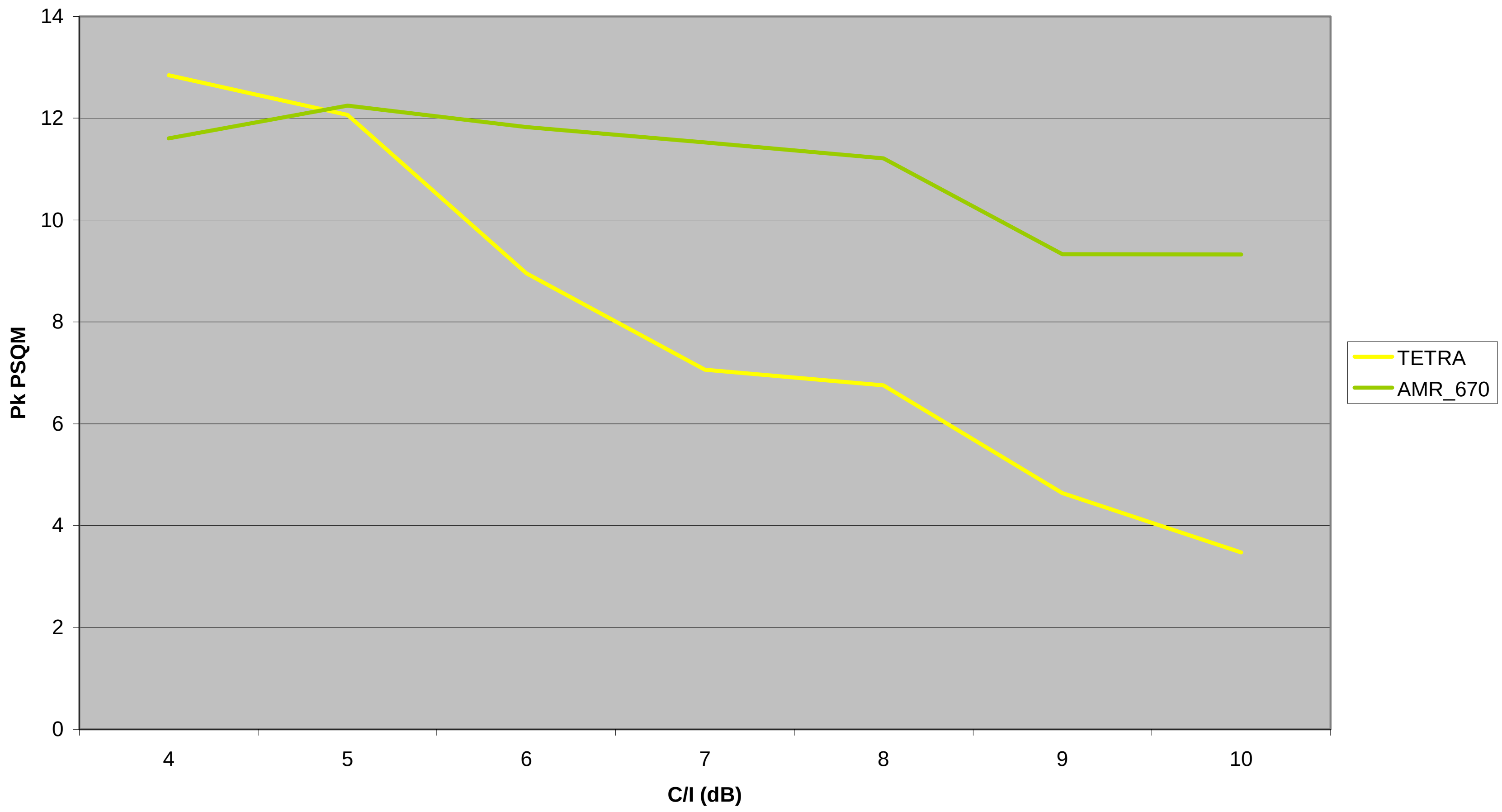

Figure 8.26: Performance of the 3GPP/GSM AMR 6,7 kbit/s Mode for the Static Channel in Terms of Peak PSQM

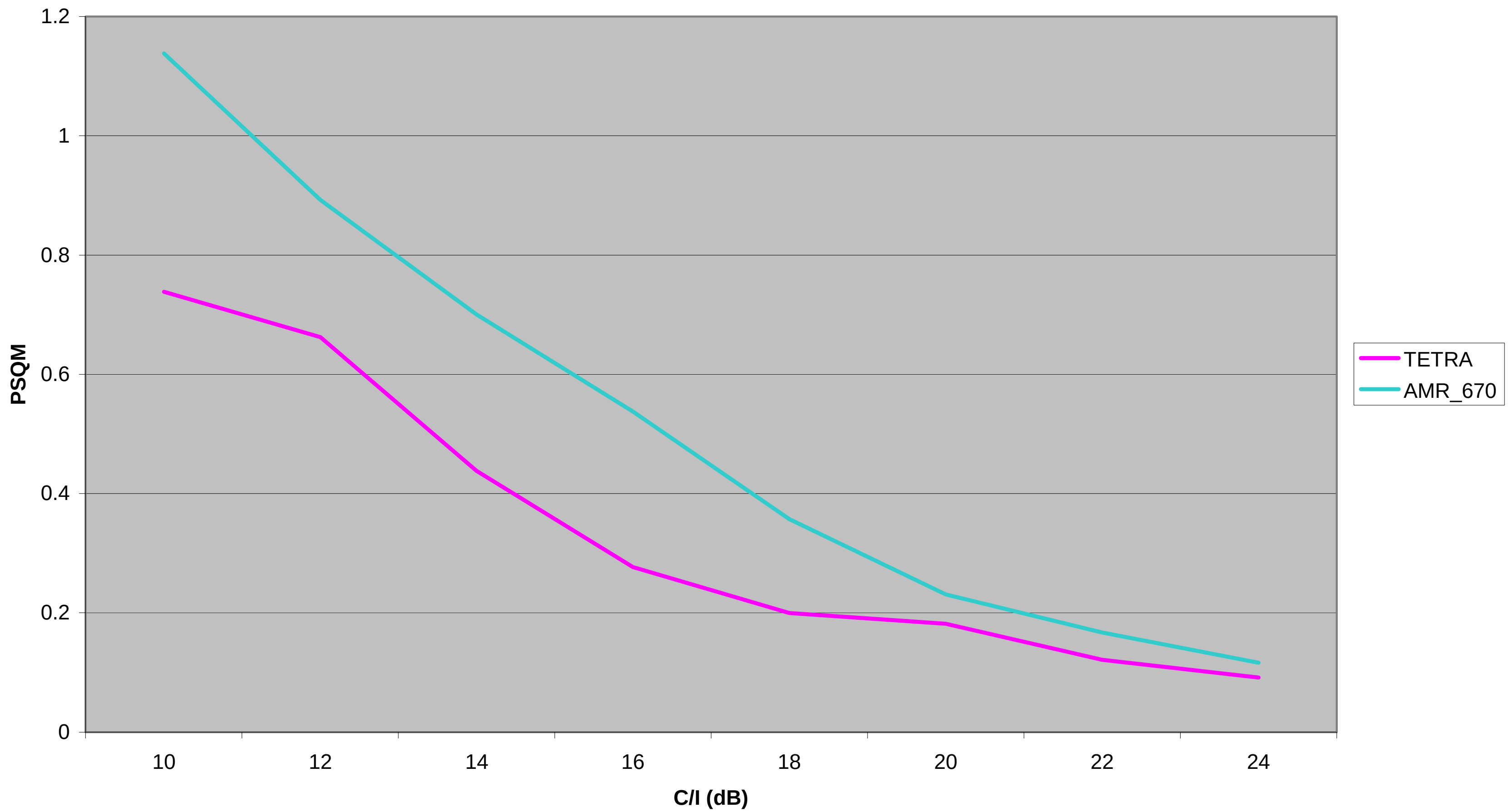

Figure 8.27: Performance of the 3GPP/GSM AMR 6,7 kbit/s Mode for the TU5 Channel in Terms of PSQM

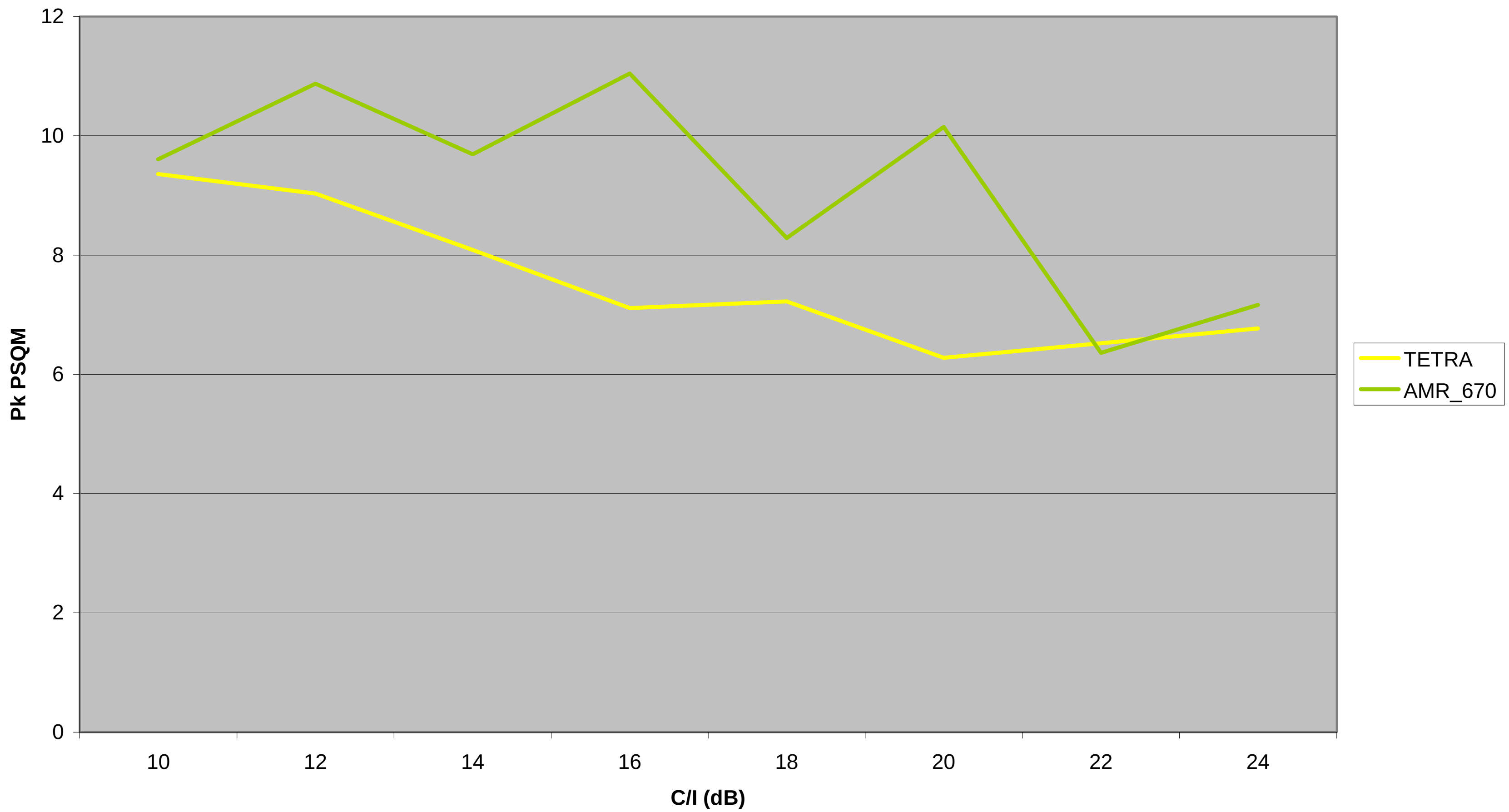

Figure 8.28: Performance of the 3GPP/GSM AMR 6,7 kbit/s Mode for the TU5 Channel in Terms of Peak PSQM

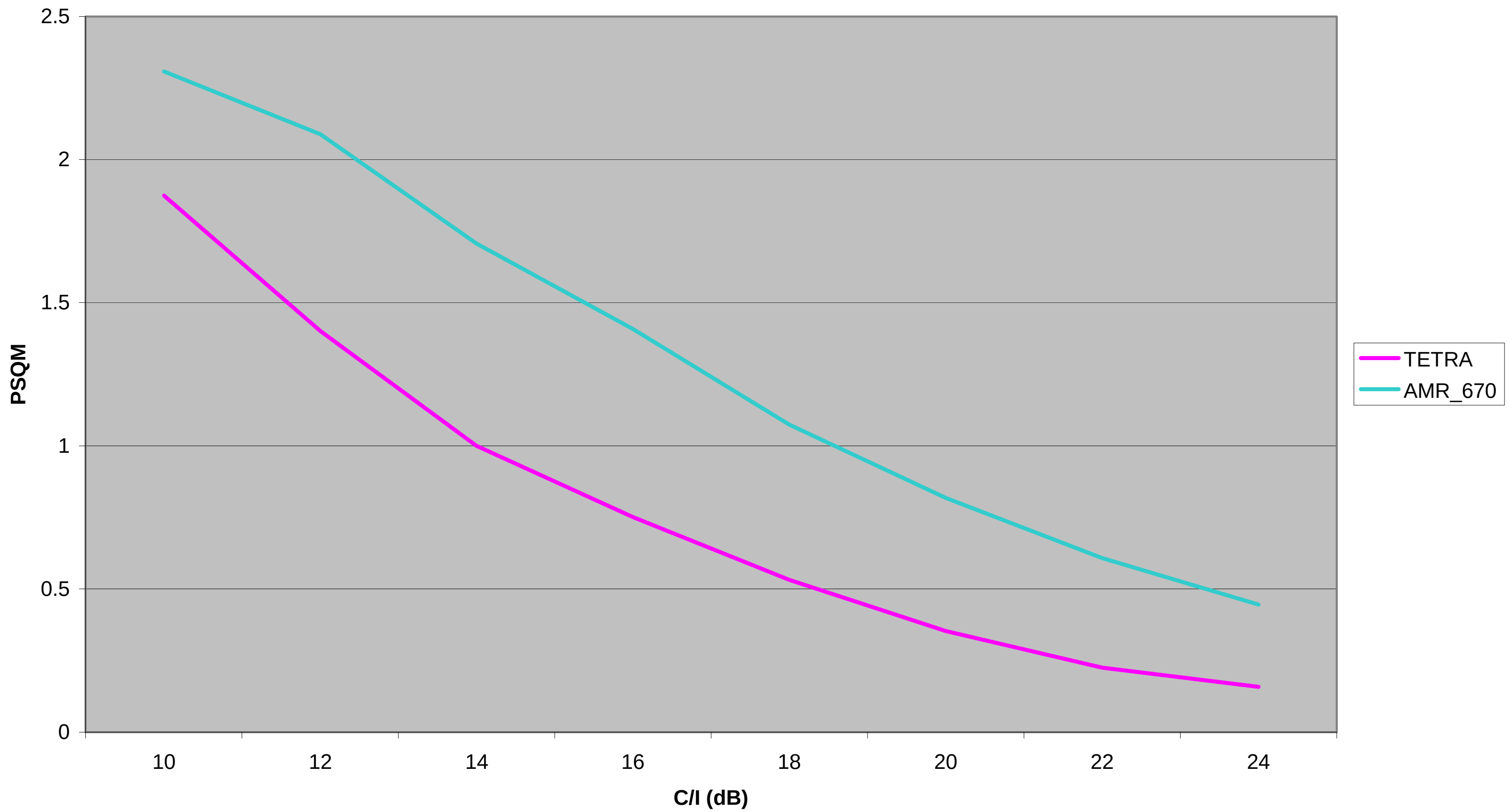

Figure 8.29: Performance of the 3GPP/GSM AMR 6,7 kbit/s Mode for the TU50 Channel in Terms of PSQM

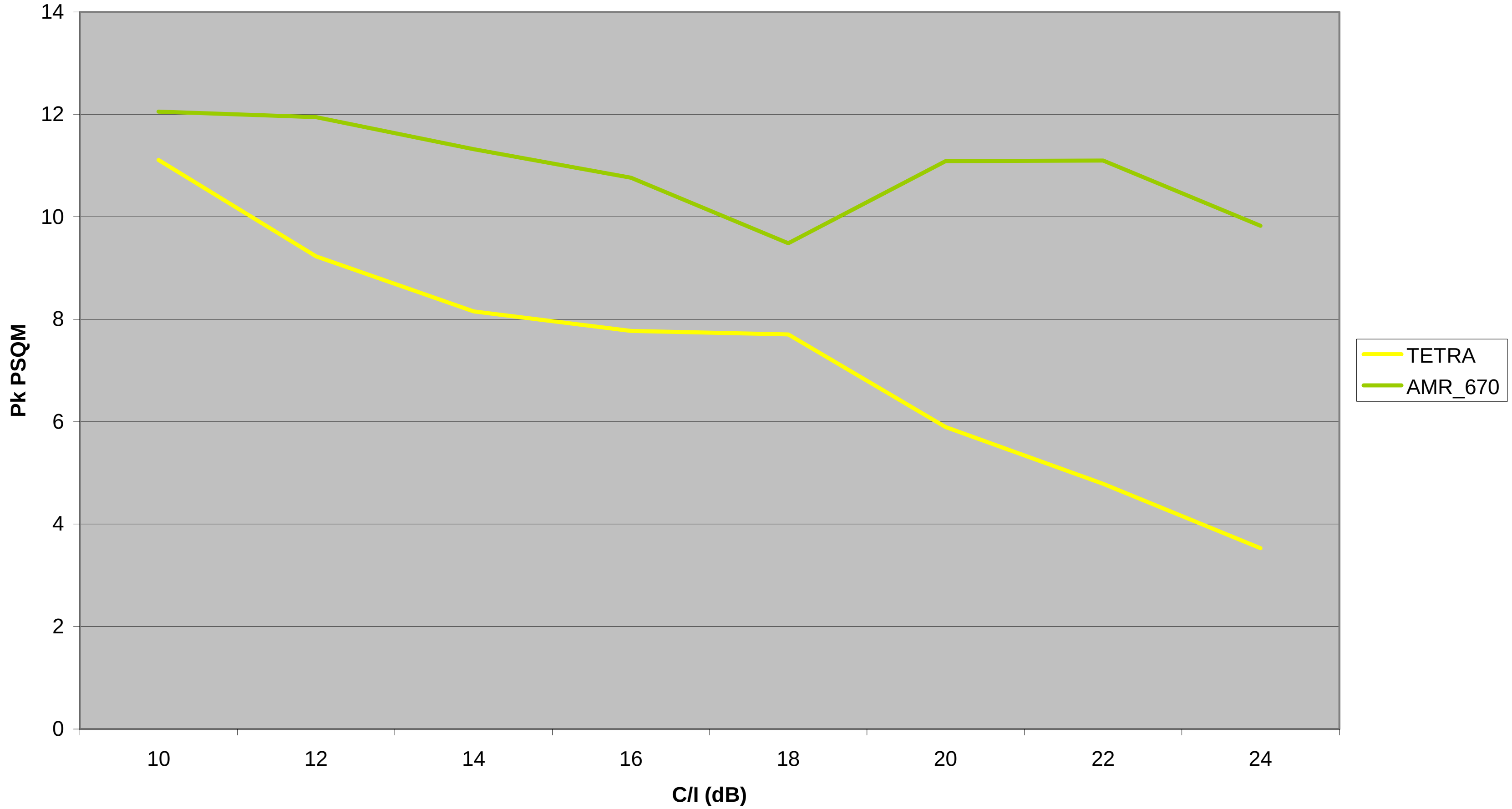

Figure 8.30: Performance of the 3GPP/GSM AMR 6,7 kbit/s Mode for the TU50 Channel in Terms of Peak PSQM

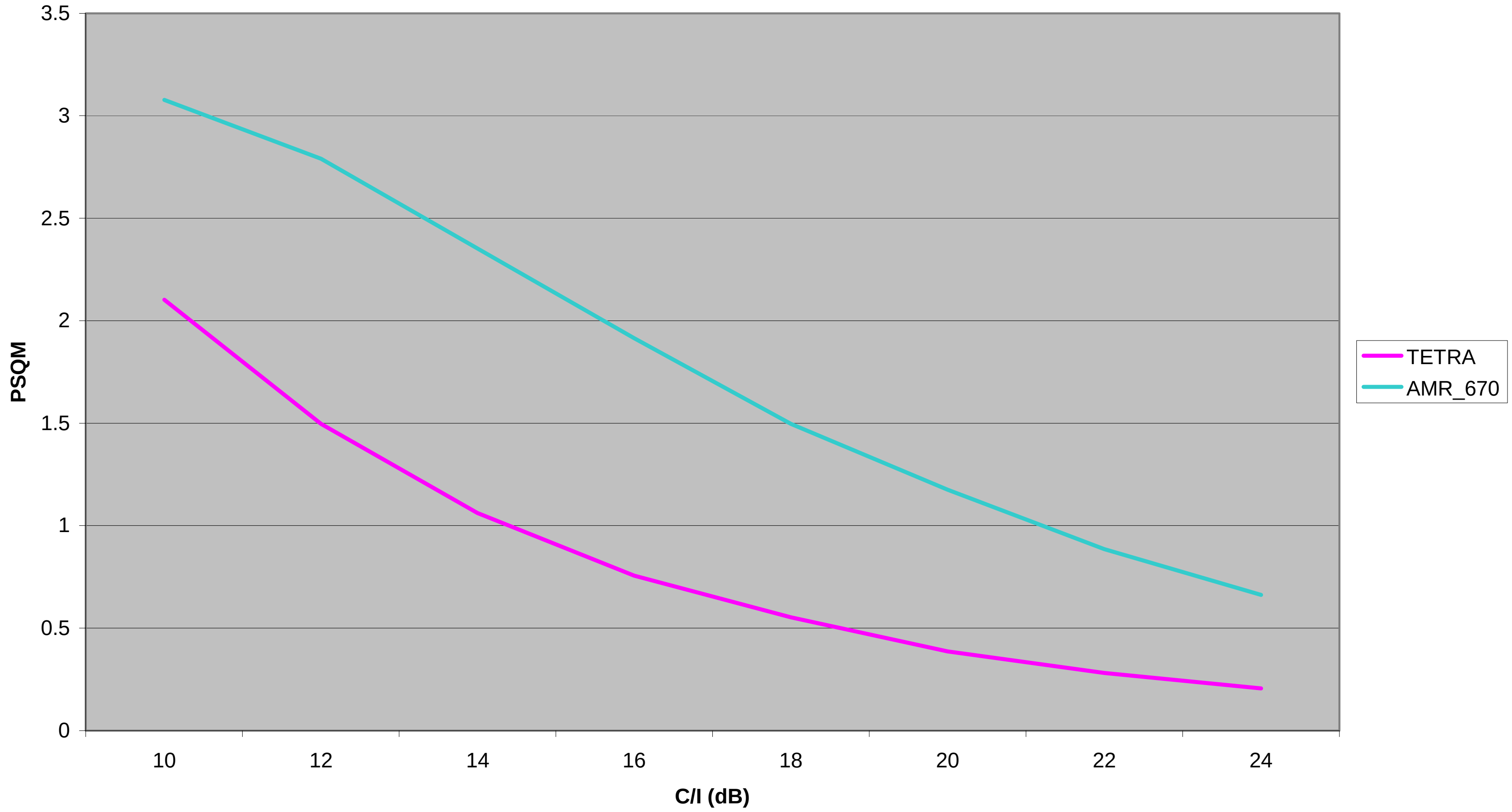

Figure 8.31: Performance of the 3GPP/GSM AMR 6,7 kbit/s Mode for the HT200 Channel in Terms of PSQM

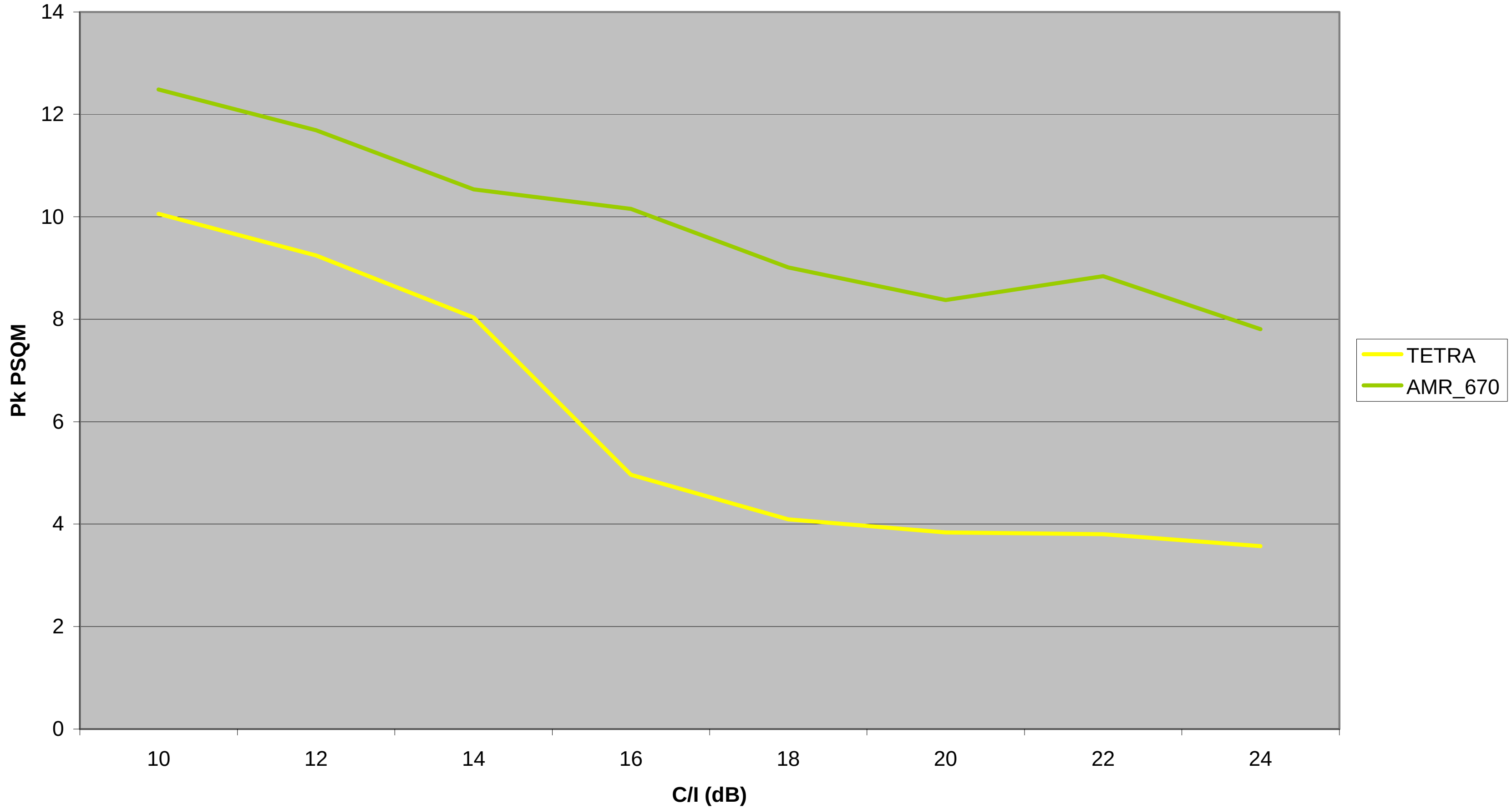

Figure 8.32: Performance of the 3GPP/GSM AMR 6,7 kbit/s Mode for the HT200 Channel in Terms of Peak PSQM

8.5 Performance of the Selected FEC Schemes

The results of the comparing the error-free speech with the channel impaired speech using ITU-T Recommendation P.861 [1] for the selected FEC schemes for all modes are shown in figures 8.33 to 8.40.

The closeness of the performance of the 4,75 kbit/s mode and the TETRA Codec is apparent with little degradation across all channel conditions for both the PSQM and Peak PSQM metrics.

There is a clear degradation of PSQM and Peak PSQM with bit rate in these figures. The 5,15 kbit/s mode is 1-2 dB worse than either TETRA or the 4,75 kbit/s mode. The 5,9 kbit/s mode is 2-4 dB worse than either TETRA or the 4,75 kbit/s mode and the 6,7 kbit/s mode is 4-6 dB worse than TETRA or the 4,75 kbit/s mode.

An additional set of results was obtained by evaluating the ITU-T Recommendation P.861 [1] distortions with reference to the unprocessed original speech (time-aligned). This resulted in the plots in figures 8.41 to 8.48 for the Peak-PSQM and PSQM scores. Ideally these figures should reflect the true apparent quality of the codec and FEC operating together, under each channel condition.

The figures appear to show that the 4,75 kbit/s mode out-performs the TETRA Codec under all conditions, except the 18dB C/I point for TU5 according to the Peak PSQM metric, where the difference is very small.

Over the range of C/I conditions tested and over the range of channel types, the 5,15 kbit/s mode appears to show little consistent performance improvement over the 4,75 kbit/s mode.

The 5,9 kbit/s and 6,7 kbit/s modes appear to demonstrate an improvement over the 4,75 kbit/s mode according to the PSQM metric for high C/I conditions, although in terms of the Peak PSQM metric, only the 5,9 kbit/s mode comes close to matching the performance of the 4,75 kbit/s mode. This tends to suggest that the quality of the speech is marred by several large distortions, rather than a consistent low level of degradation which may prove to be disturbing to listeners.

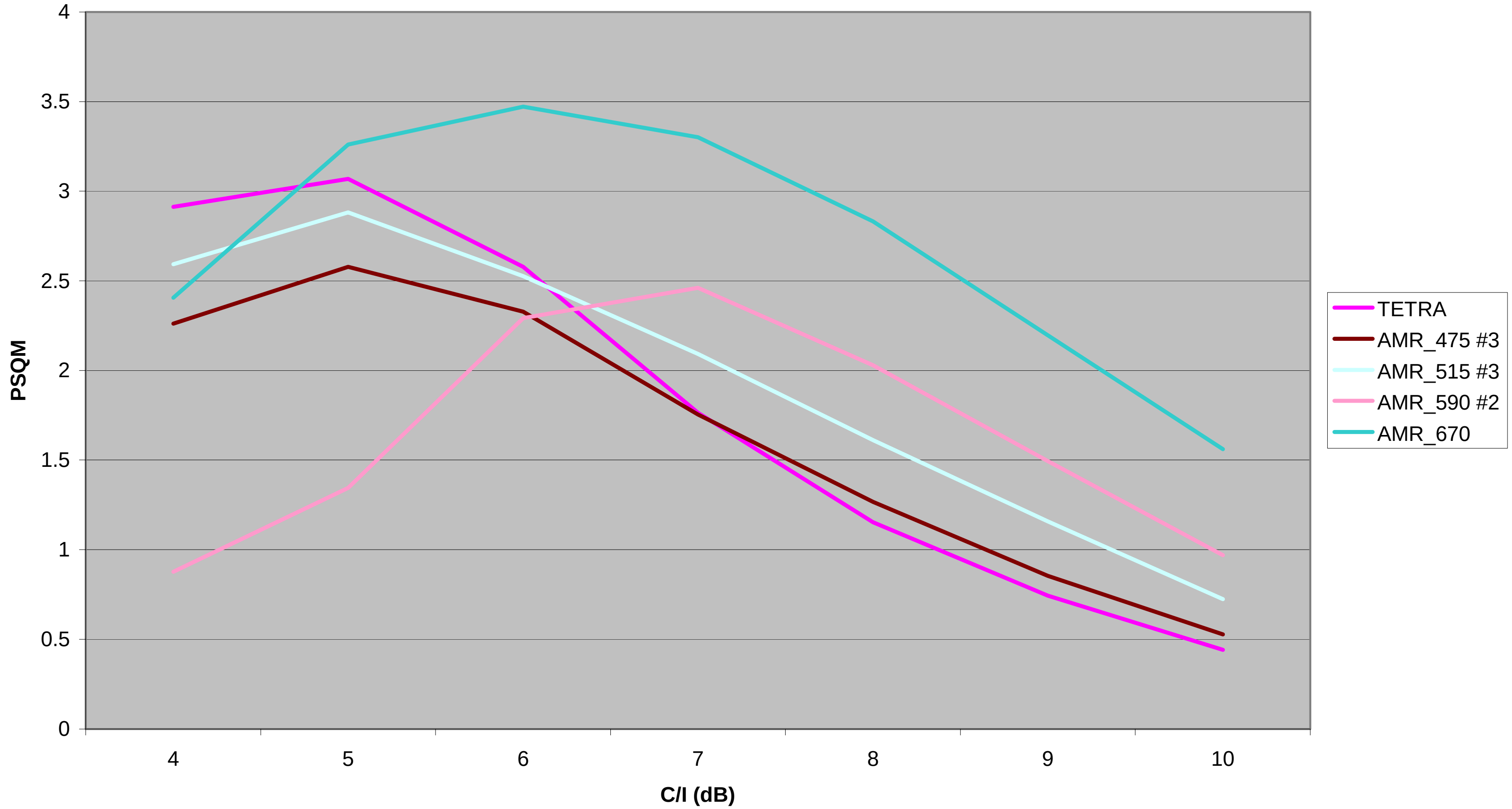

Figure 8.33: Performance of the Selected FEC Schemes for the 3GPP/GSM AMR Modes for the Static Channel in Terms of PSQM (Error-Free Reference)

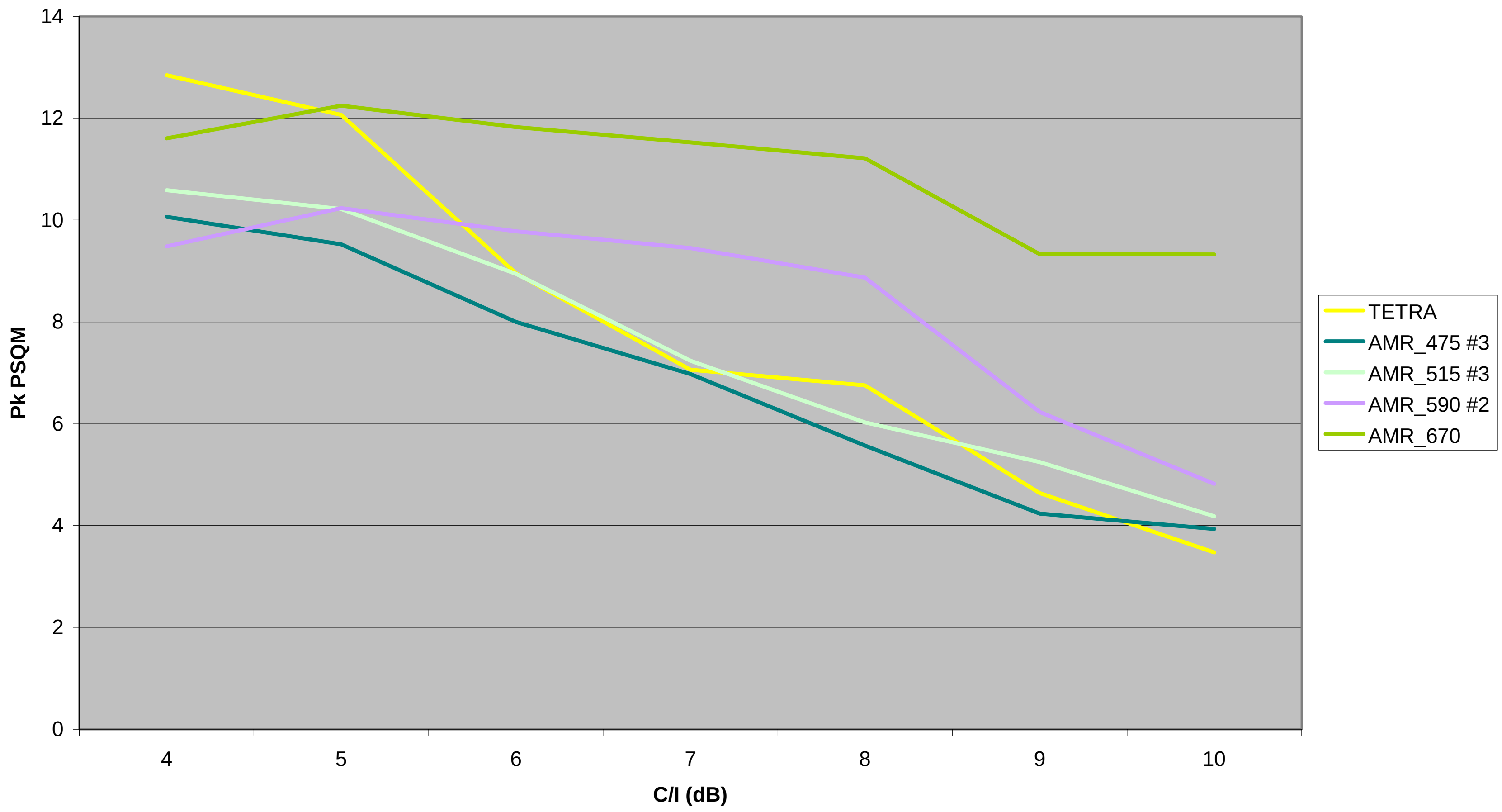

Figure 8.34: Performance of the Selected FEC Schemes for the 3GPP/GSM AMR Modes for the Static Channel in Terms of Peak PSQM (Error-Free Reference)

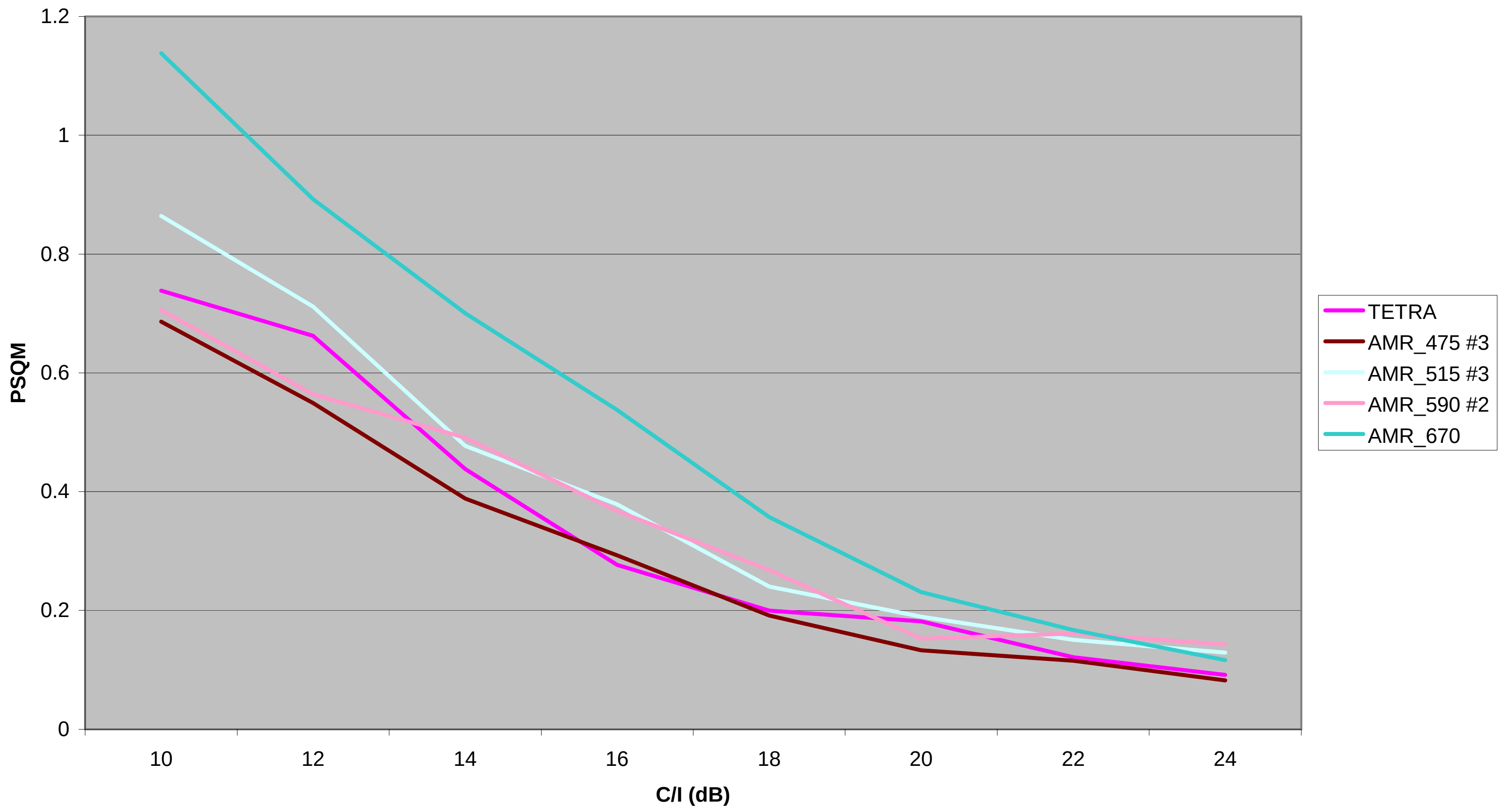

Figure 8.35: Performance of the Selected FEC Schemes for the 3GPP/GSM AMR Modes for the TU5 Channel in Terms of PSQM (Error-Free Reference)

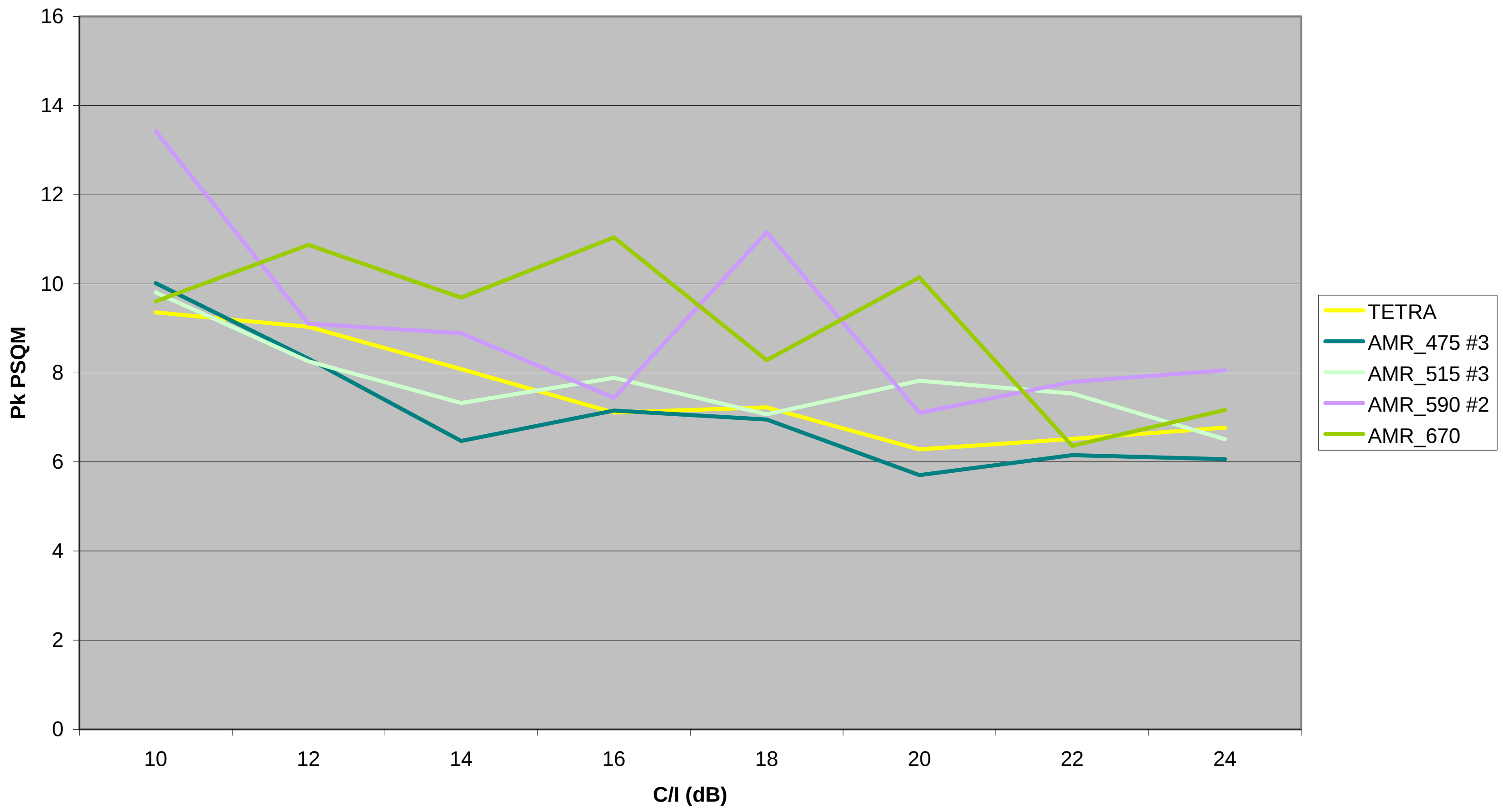

Figure 8.36: Performance of the Selected FEC Schemes for the 3GPP/GSM AMR Modes for the TU5 Channel in Terms of Peak PSQM (Error-Free Reference)

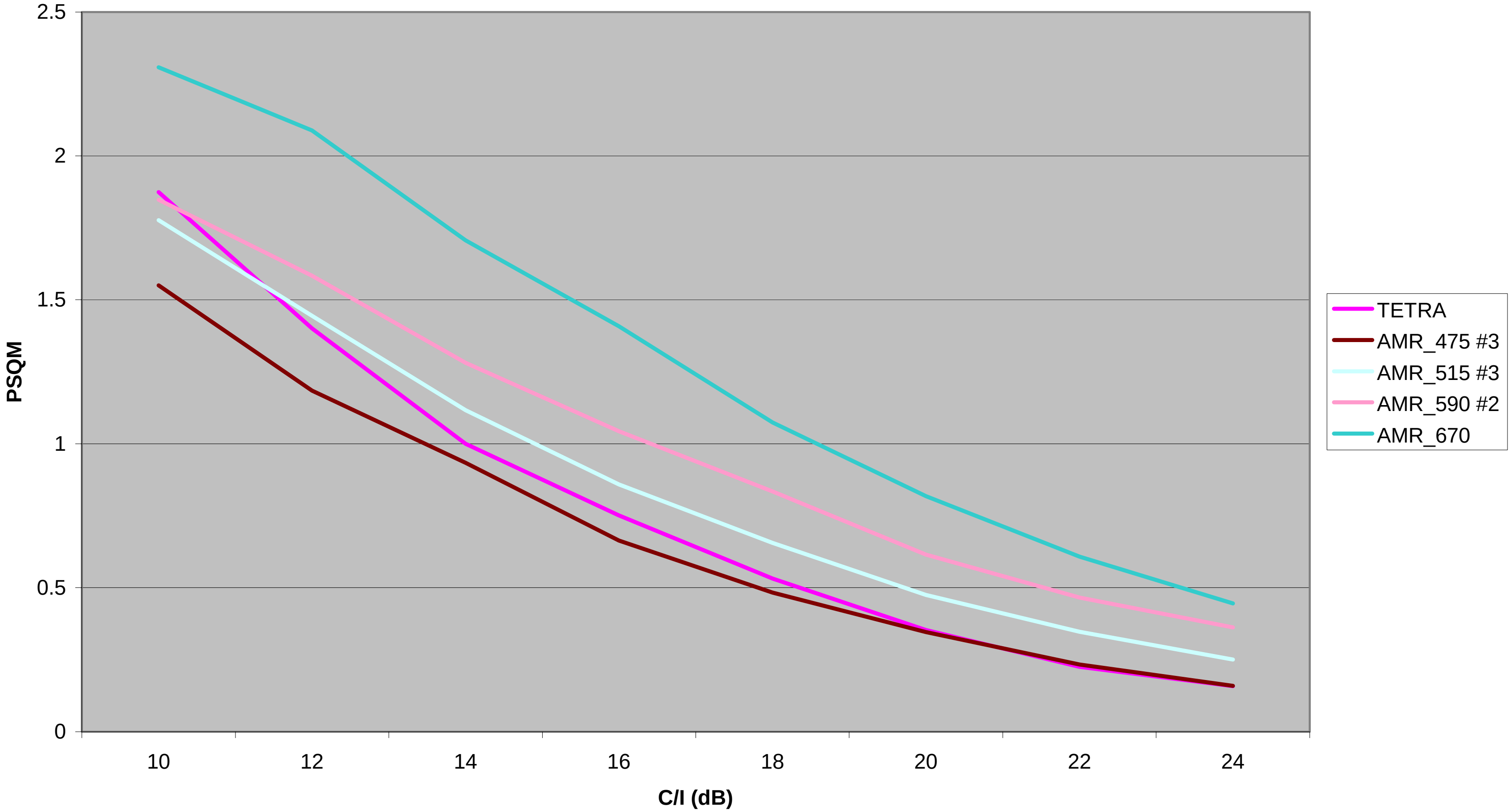

Figure 8.37: Performance of the Selected FEC Schemes for the 3GPP/GSM AMR Modes for the TU50 Channel in Terms of PSQM (Error-Free Reference)

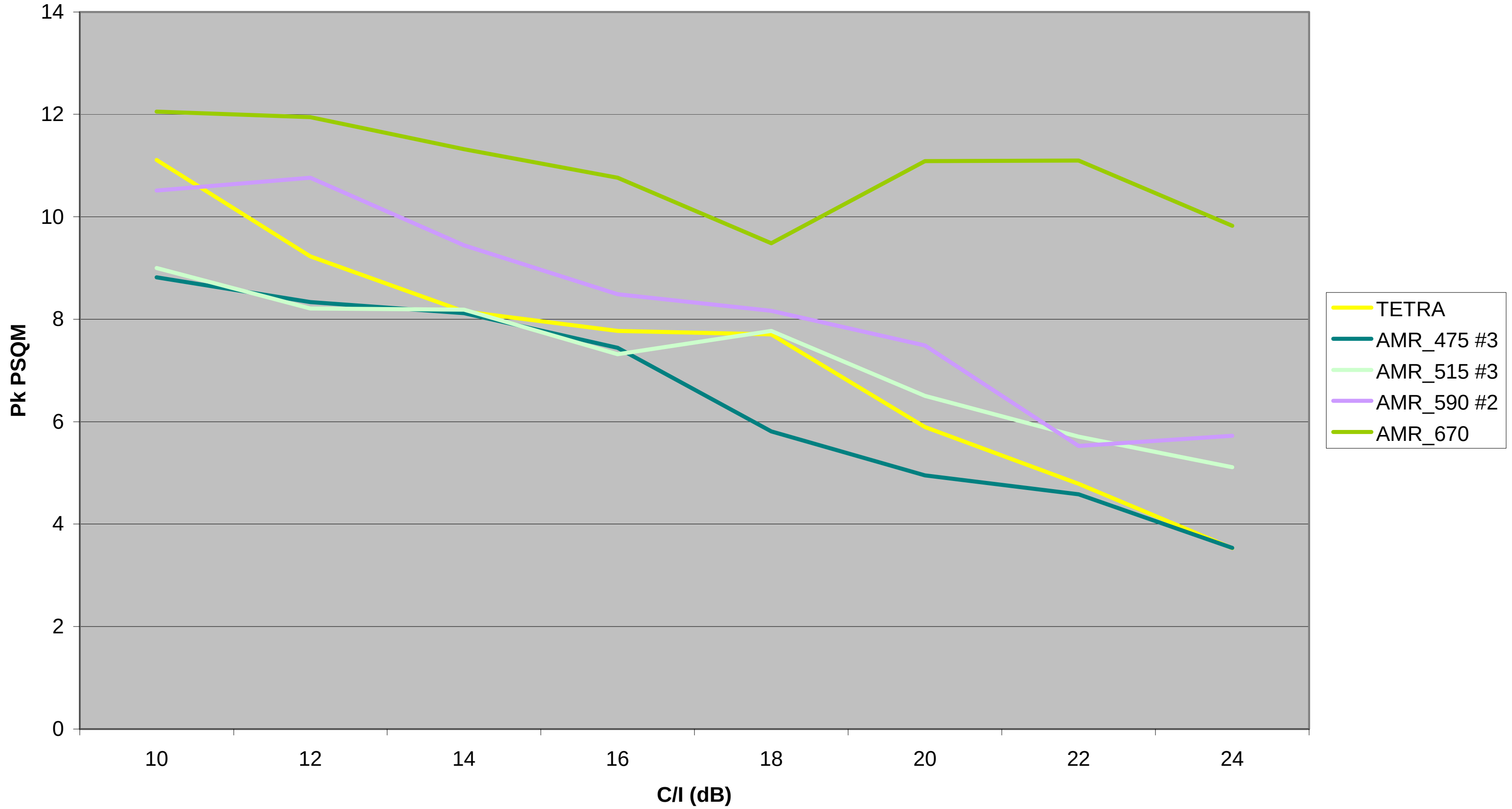

Figure 8.38: Performance of the Selected FEC Schemes for the 3GPP/GSM AMR Modes for the TU50 Channel in Terms of Peak PSQM (Error-Free Reference)

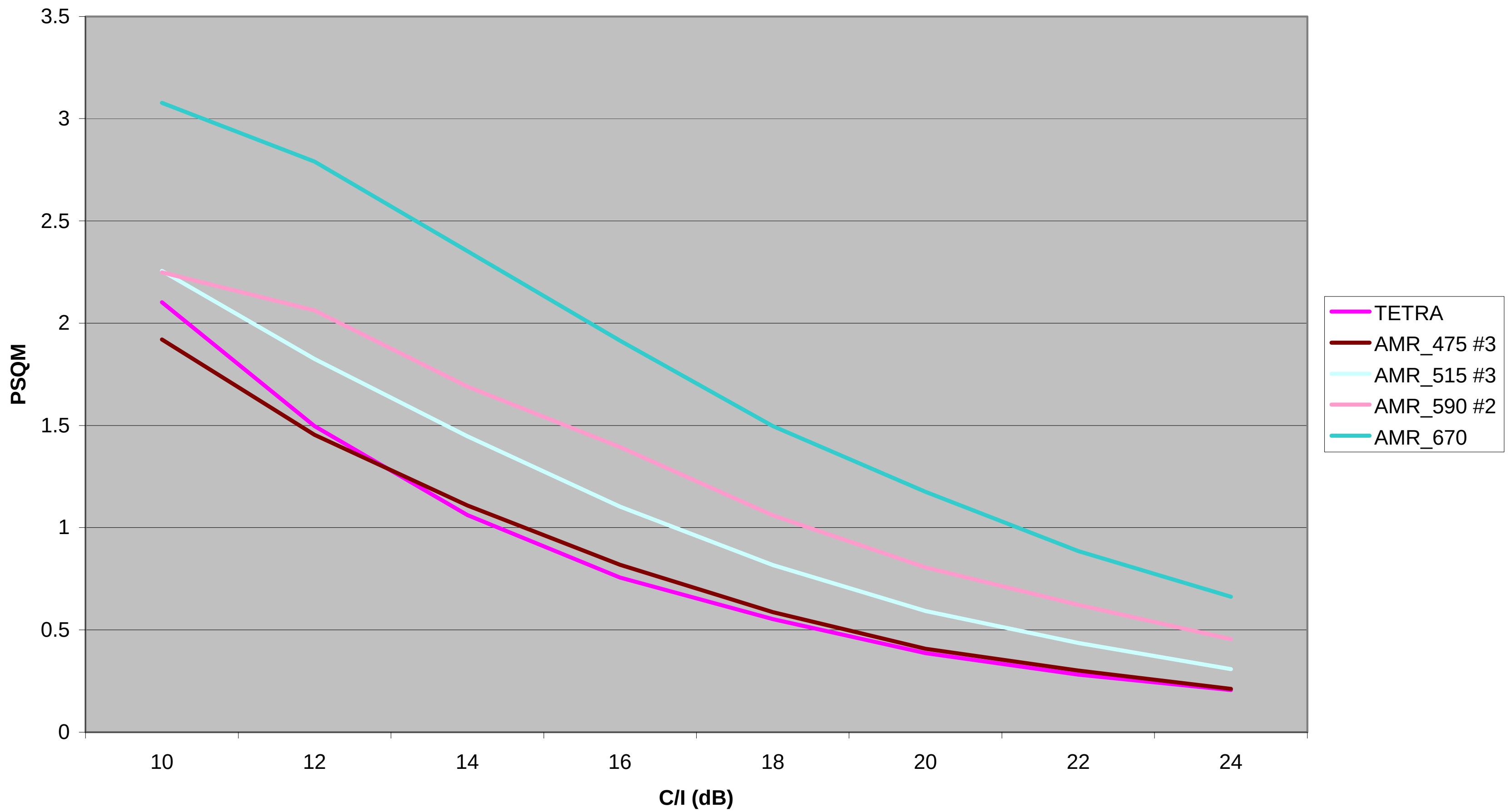

Figure 8.39: Performance of the Selected FEC Schemes for the 3GPP/GSM AMR Modes for the HT200 Channel in Terms of PSQM (Error-Free Reference)

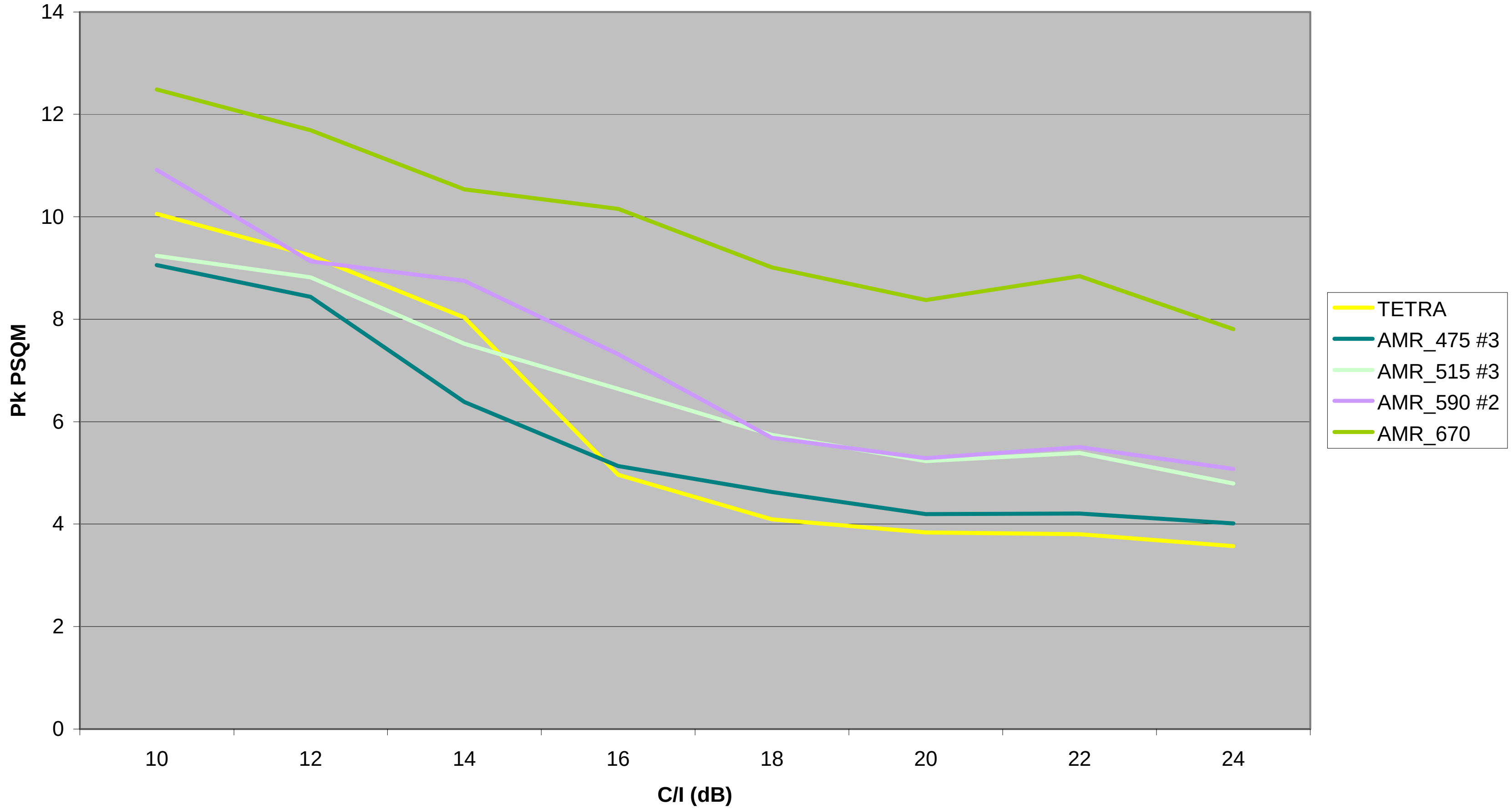

Figure 8.40: Performance of the Selected FEC Schemes for the 3GPP/GSM AMR Modes for the HT200 Channel in Terms of Peak PSQM (Error-Free Reference)

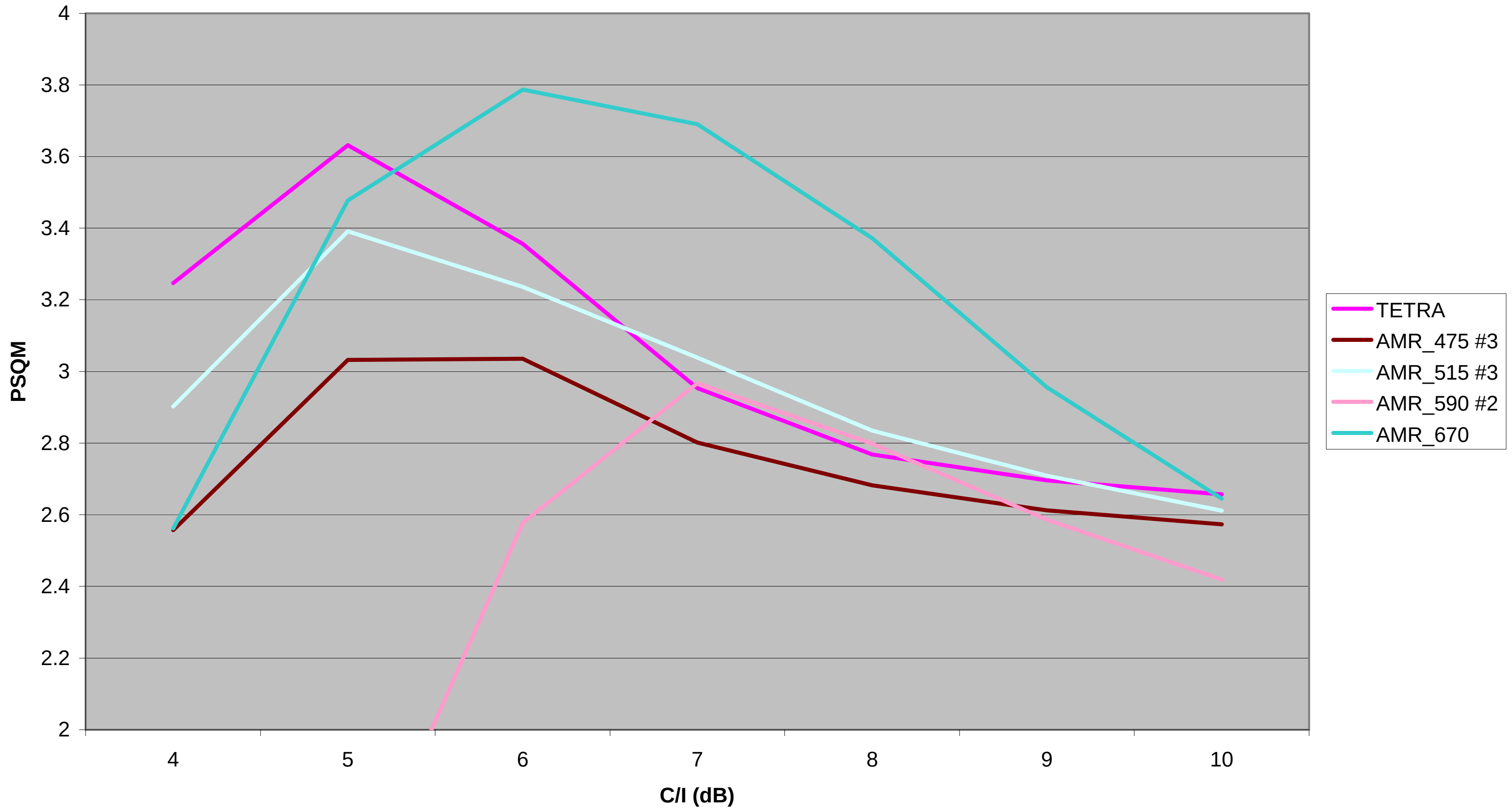

Figure 8.41: Performance of the Selected FEC Schemes for the 3GPP/GSM AMR Modes for the Static Channel in Terms of PSQM (Unprocessed Reference)

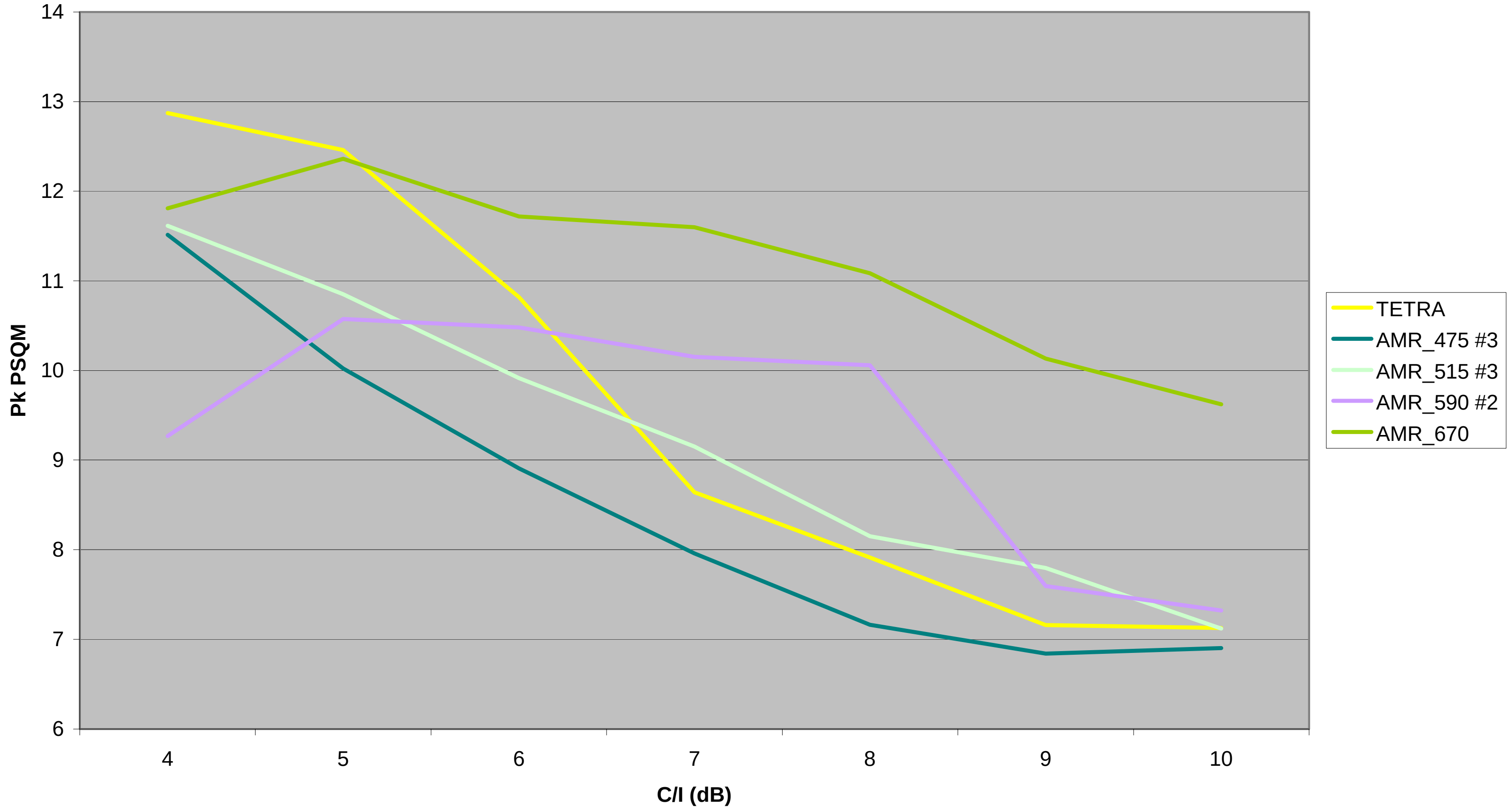

Figure 8.42: Performance of the Selected FEC Schemes for the 3GPP/GSM AMR Modes for the Static Channel in Terms of Peak PSQM (Unprocessed Reference)

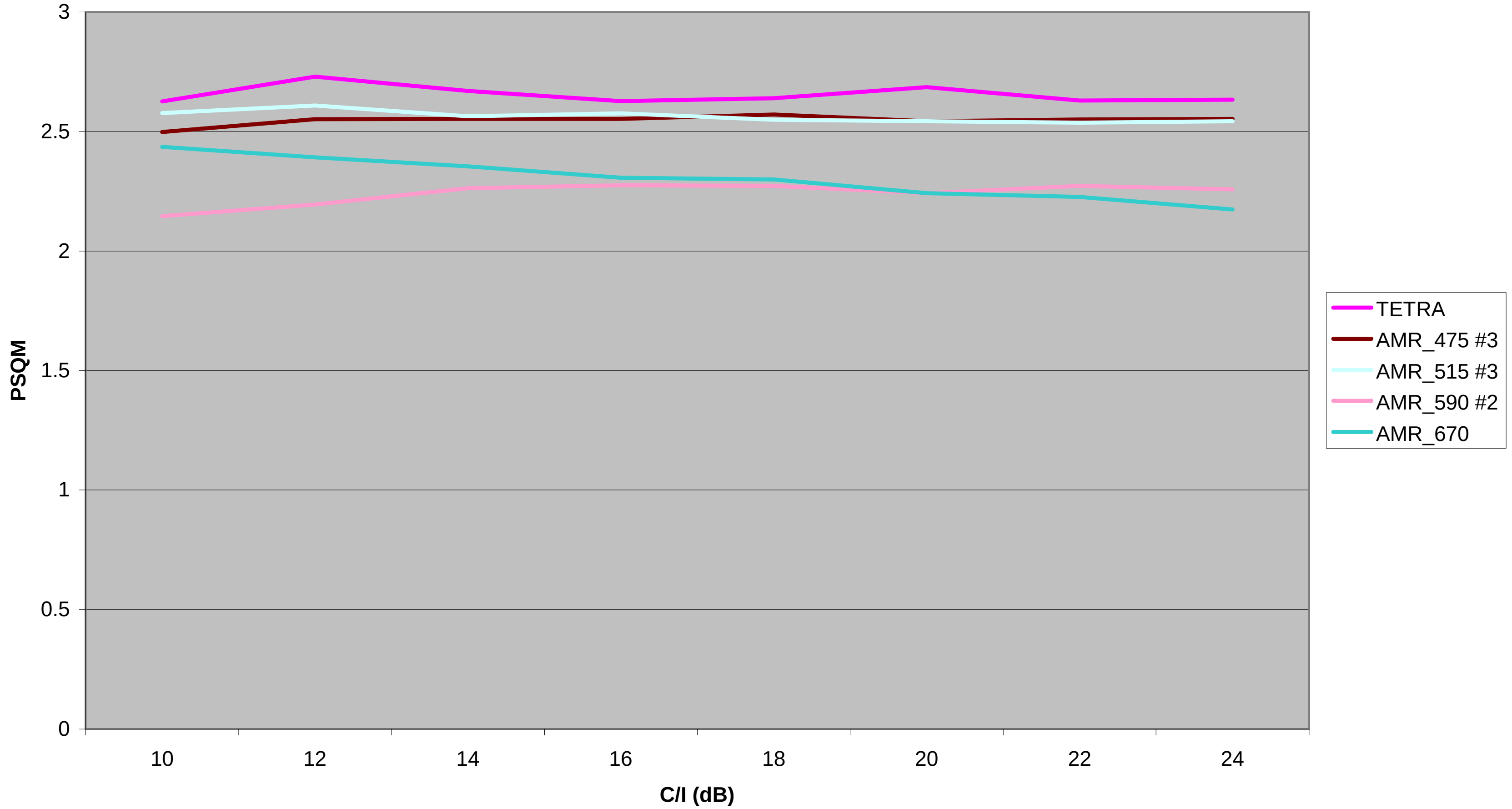

Figure 8.43: Performance of the Selected FEC Schemes for the 3GPP/GSM AMR Modes for the TU5 Channel in Terms of PSQM (Unprocessed Reference)

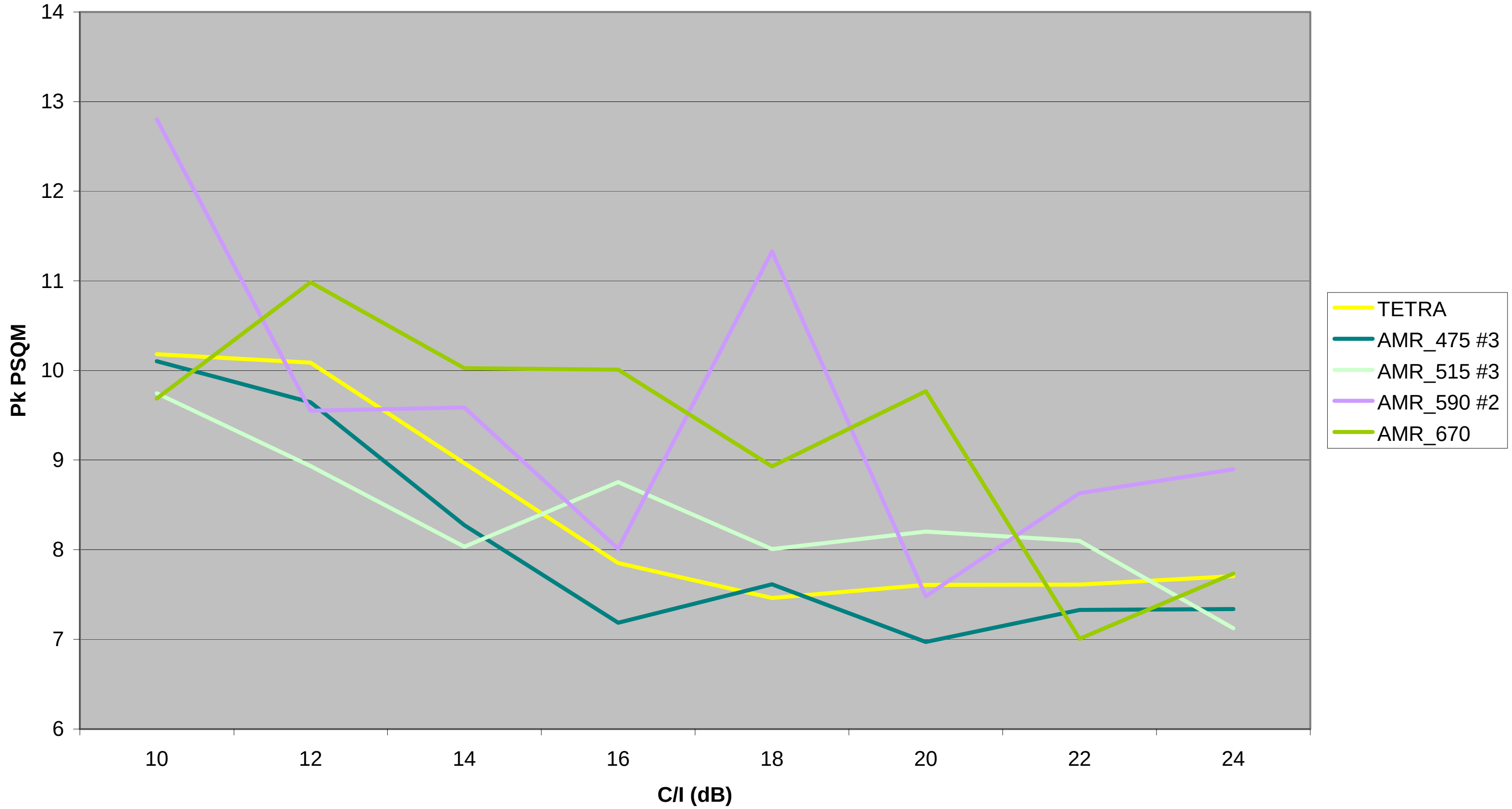

Figure 8.44: Performance of the Selected FEC Schemes for the 3GPP/GSM AMR Modes for the TU5 Channel in Terms of Peak PSQM (Unprocessed Reference)

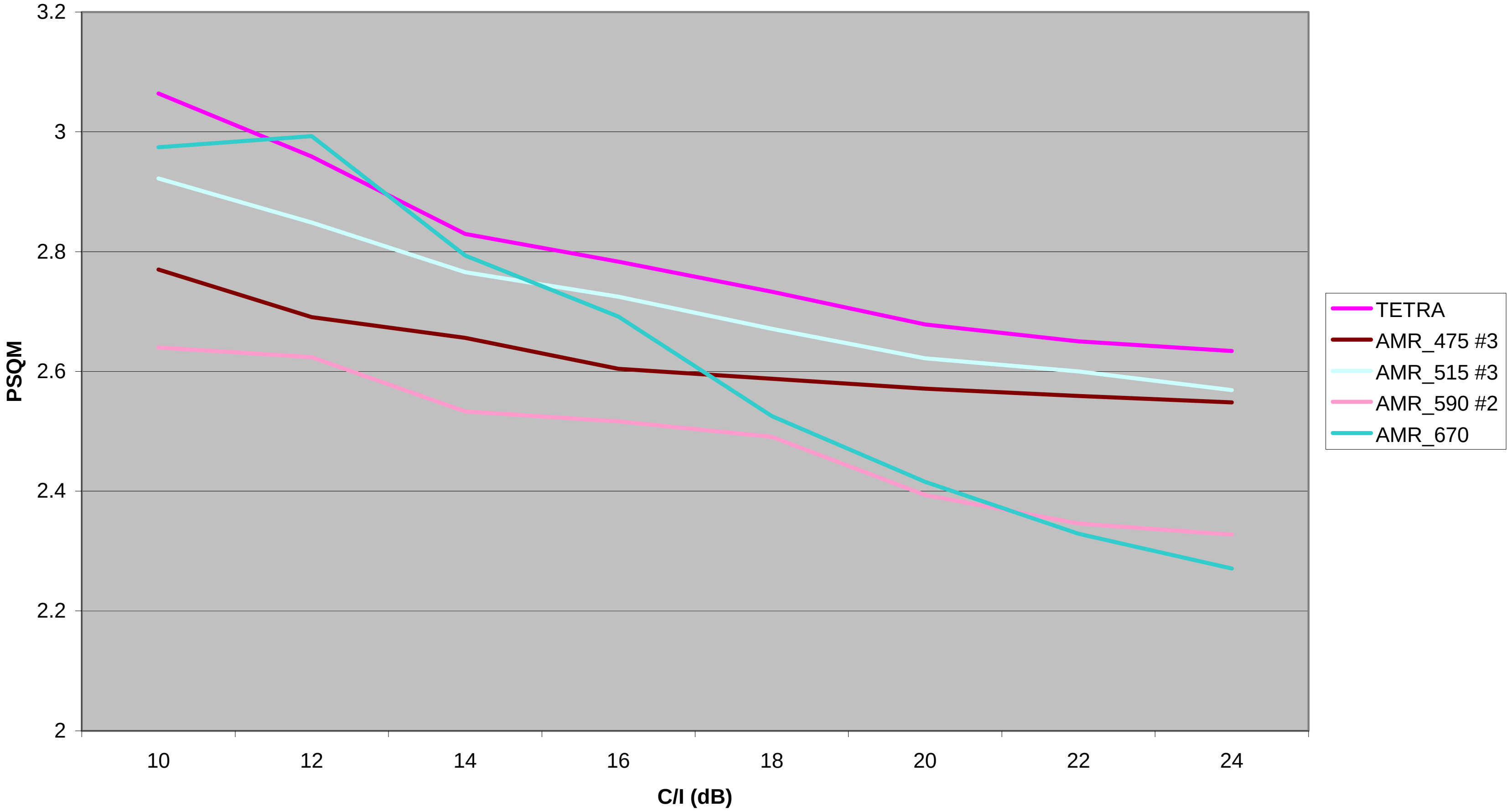

Figure 8.45: Performance of the Selected FEC Schemes for the 3GPP/GSM AMR Modes for the TU50 Channel in Terms of PSQM (Unprocessed Reference)

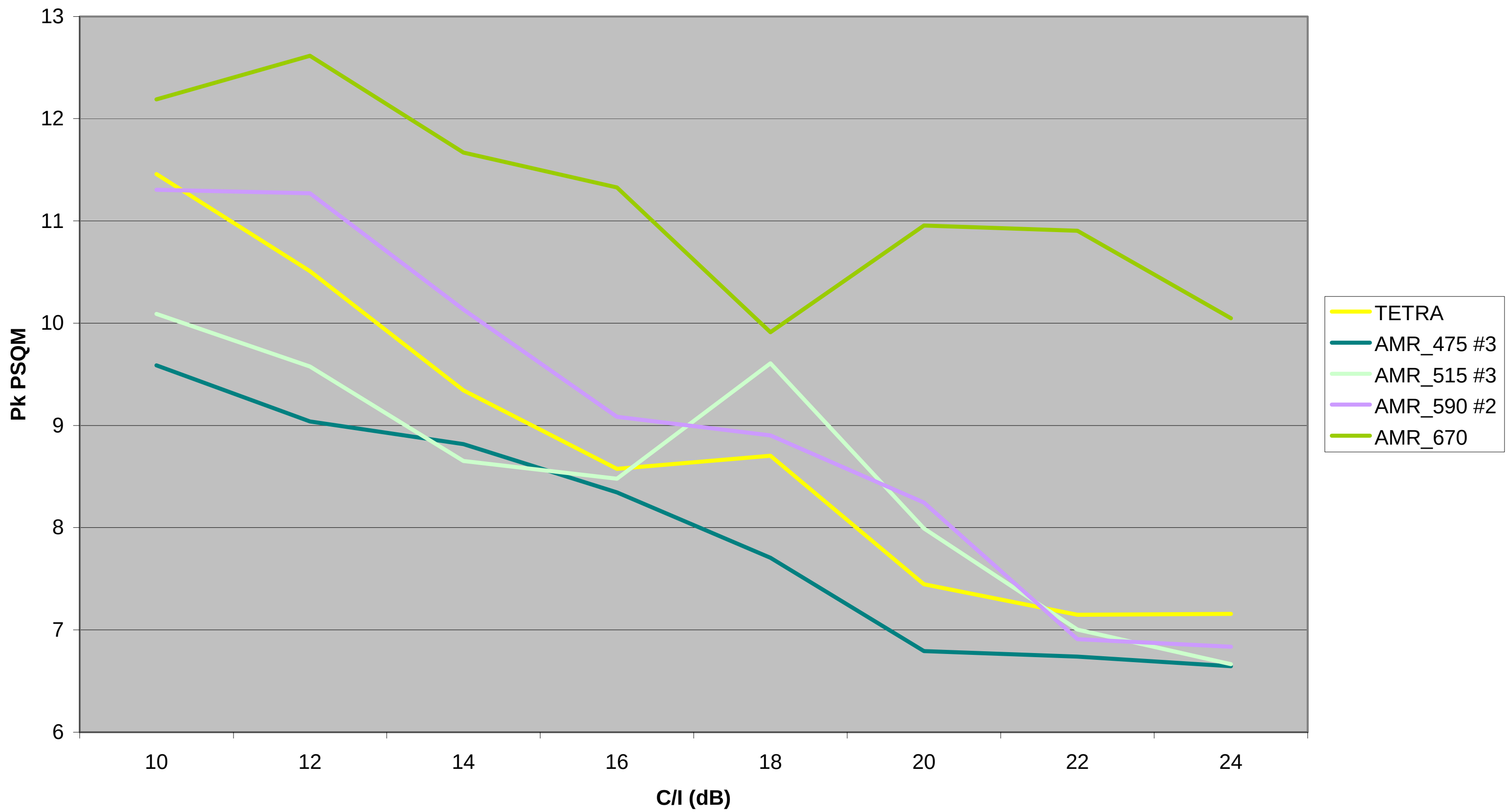

Figure 8.46: Performance of the Selected FEC Schemes for the 3GPP/GSM AMR Modes for the TU50 Channel in Terms of Peak PSQM (Unprocessed Reference)

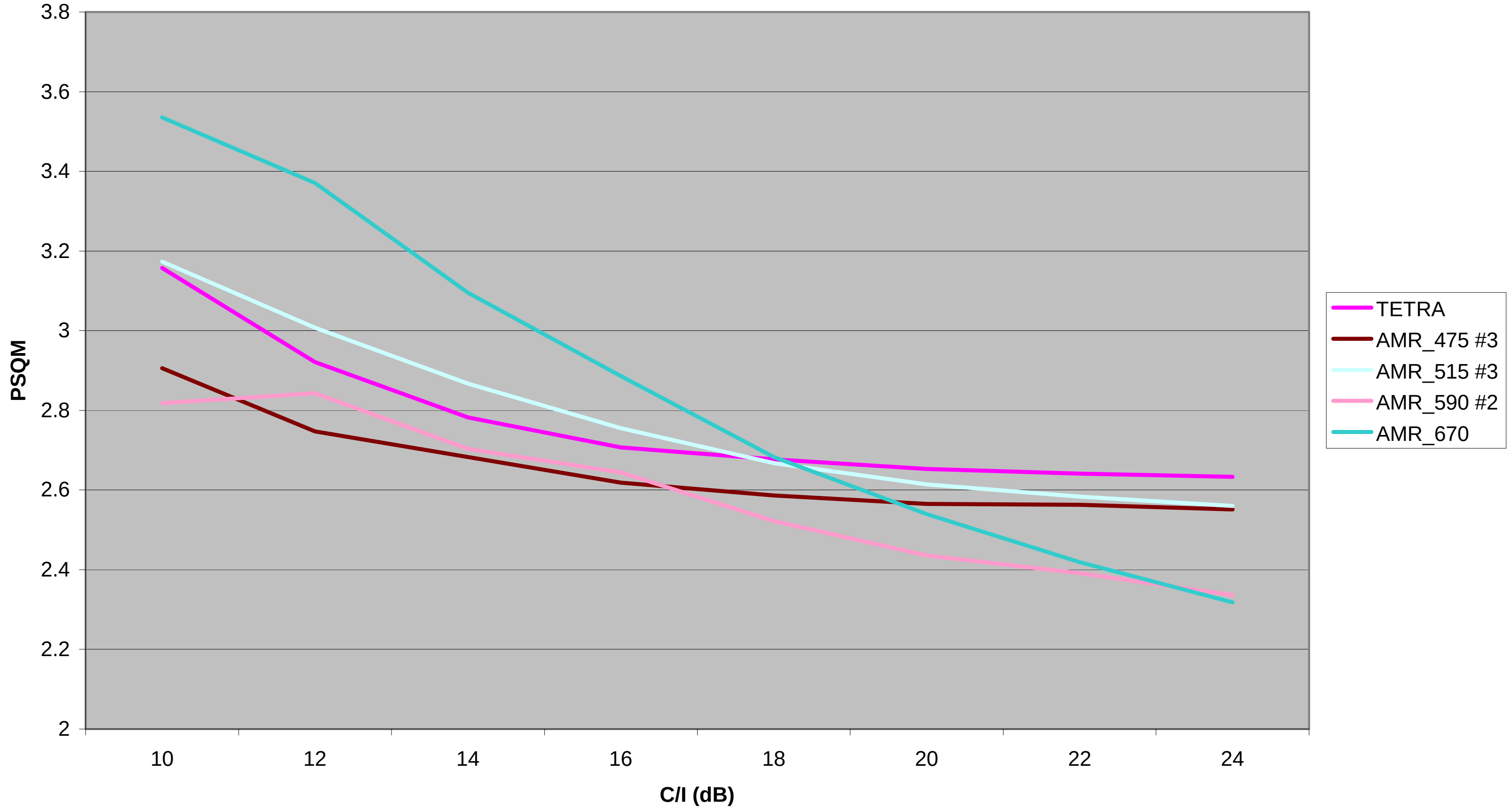

Figure 8.47: Performance of the Selected FEC Schemes for the 3GPP/GSM AMR Modes for the HT200 Channel in Terms of PSQM (Unprocessed Reference)

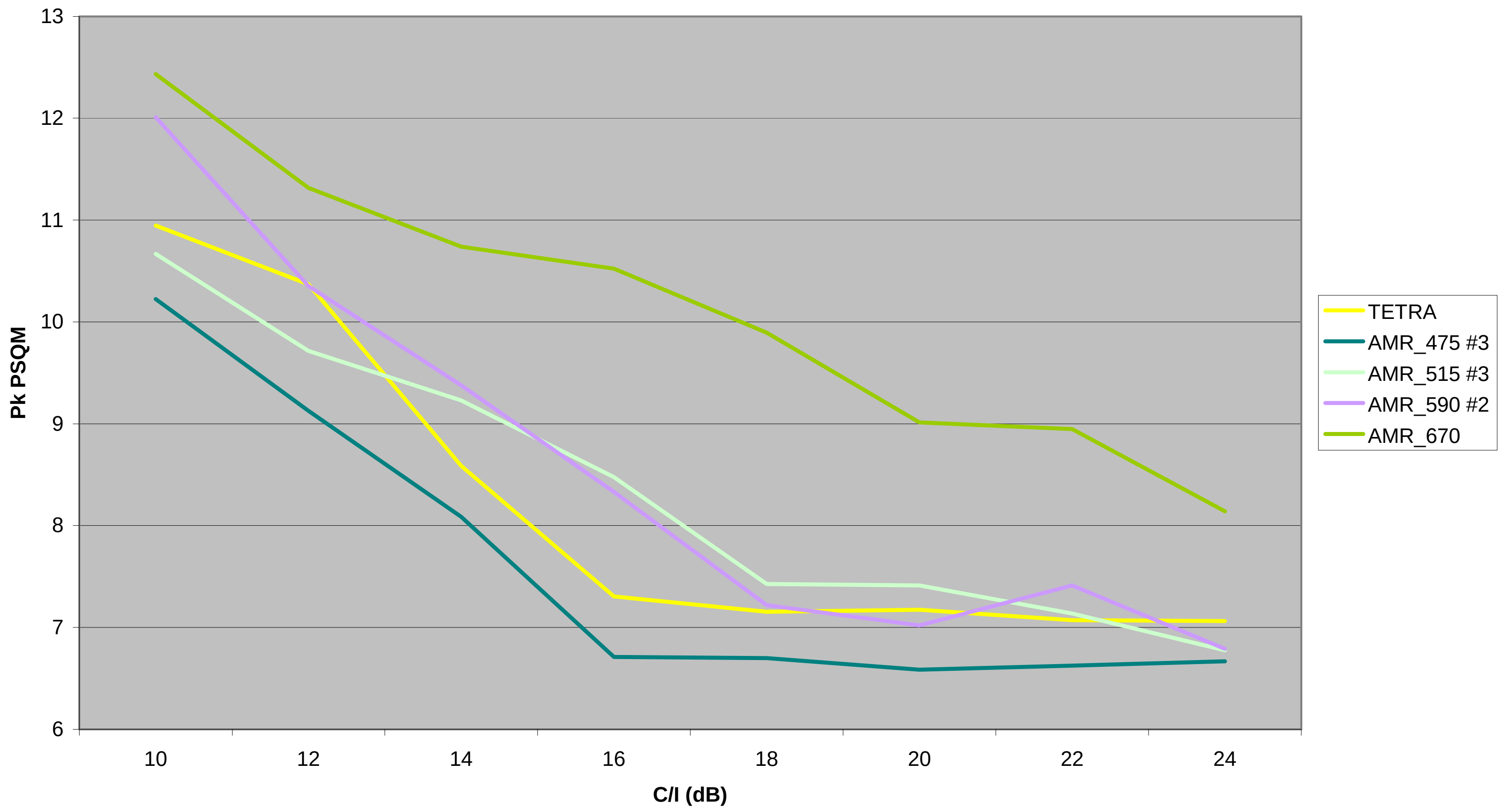

Figure 8.48: Performance of the Selected FEC Schemes for the 3GPP/GSM AMR Modes for the HT200 Channel in Terms of Peak PSQM (Unprocessed Reference)

9 Results of expert listening tests for the TETRA and AMR codecs

The main aim for the informal expert listening was to determine the degree to which the various ITU-T Recommendation P.861 [1] comparisons could be interpreted as reflecting true perceptual quality.

It was hoped that out of this listening would emerge a list of AMR modes which were appropriate for inclusion in TETRA and an estimate of the proportion of the coverage area for which those modes would provide a quality improvement.

For the purposes of listening, a 32 second speech file comprising 8 speakers and 12 sentences was used.

9.1 4,75 kbit/s Mode

For the 4,75 kbit/s mode, two listening experiments were performed. The first was a preference test on a three-point scale comparing TETRA to the AMR 4,75 kbit/s mode in a pair-wise fashion. The three possible options were; a) 4.75 Mode preferred to TETRA, b) TETRA preferred to the 4.75 Mode, or c) similar quality. The second test was to establish an approximate threshold of intelligibility/acceptability for the two codecs. Listening was only meaningful over the Static, TU50 and HT200 channels since the fade rate of the TU5 channel was too slow for meaningful statistics to be gathered.

The results are presented as a ratio of preference; 50:50 indicating that the two codecs were of equal quality on average or had the same number of preference votes, 100:0 indicating that the first codec was preferred in all instances.

Table 9.1: Results of Expert Informal Listening for the 4,75 kbit/s AMR Mode – Shaded Cells Below Level of Intelligibility

Static Channel		TU50 Channel		HT200 Channel	
C/I (dB)	AMR 4,75 : TETRA	C/I (dB)	AMR 4,75 : TETRA	C/I (dB)	AMR 4,75: TETRA
4	50 : 50	10	58 : 42	10	29 : 71
5	29 : 71	12	71 : 29	12	50 : 50
6	46 : 54	14	67 : 33	14	54 : 46
7	67 : 33	16	71 : 29	16	79 : 21
8	83 : 17	18	67 : 33	18	83 : 17
9	83 : 17	20	83 : 17	20	88 : 12
10	92 : 8	22	83 : 17	22	100 : 0
		24	96 : 4	24	100 : 0

The results show that the apart from 5dB C/I for the static channel and the 10 dB C/I HT200 channel conditions, the AMR 4,75 kbit/s Codec is equivalent to, or better than, the TETRA Codec. In some cases the preference is very strong, particularly in high C/I conditions.

When the limit of intelligibility/acceptability is considered, (approximately 6-7 dB for the Static channel and 12-14 dB for the TU50 and HT200 channels for both the AMR 4,75 kbit/s and TETRA codecs), it can be seen that above this point, the AMR 4,75 kbit/s Codec is always preferred.

9.2 5,15 kbit/s Mode

For the 5,15 kbit/s mode, two listening experiments were performed. The first was a preference test on a three-point scale comparing the AMR 5,15 kbit/s mode to the AMR 4,75 kbit/s mode in a pair-wise fashion as described above. The second test was to establish an approximate threshold of intelligibility/acceptability for the AMR 5,15 kbit/s codec. Again, the TU5 channel was omitted.

The results are shown in table 9.2.

Table 9.2: Results of Expert Informal Listening for the 5,15 kbit/s AMR Mode – Shaded Cells Below Level of Intelligibility

Static Channel		TU50 Channel		HT200 Channel	
C/I (dB)	5,15 : 4,75	C/I (dB)	5,15 : 4,75	C/I (dB)	5,15 : 4,75
4	50 : 50	10	42 : 58	10	29 : 71
5	46 : 54	12	33 : 67	12	33 : 67
6	33 : 67	14	50 : 50	14	33 : 67
7	29 : 71	16	46 : 54	16	42 : 58
8	37 : 63	18	42 : 58	18	33 : 67
9	25 : 75	20	37 : 63	20	46 : 54
10	58 : 42	22	46 : 54	22	50 : 50
		24	54 : 46	24	54 : 46

Apart from the highest C/I condition for each of the channels, there is no preference for the 5,15 kbit/s codec over the 4,75 kbit/s mode. At high C/Is, the preference is very slightly in favour of the 5,15 kbit/s mode.

The threshold of intelligibility was judged to be approximately 6-7 dB C/I for the static channel, and 12-14 dB for the TU50 and HT200 channels.

9.3 5,9 kbit/s Mode

As for the 5,15 kbit/s mode, two listening experiments were performed for the 5,9 kbit/s mode. The first was a preference test on a three-point scale comparing the AMR 5,9 kbit/s mode to the AMR 4,75 kbit/s mode in a pair-wise fashion as described above. The second test was to establish an approximate threshold of intelligibility/acceptability for the AMR 5,9 kbit/s codec. Again, the TU5 channel was omitted.

The results are shown in table 9.3.

Table 9.3: Results of Expert Informal Listening for the 5,9 kbit/s AMR Mode – Shaded Cells Below Level of Intelligibility

Static Channel		TU50 Channel		HT200 Channel	
C/I (dB)	5,9 : 4,75	C/I (dB)	5,9 : 4,75	C/I (dB)	5,9 : 4,75
4	33 : 66	10	4 : 96	10	4 : 96
5	12 : 88	12	4 : 96	12	4 : 96
6	0 : 100	14	12 : 88	14	12 : 88
7	0 : 100	16	12 : 88	16	33 : 67
8	4 : 96	18	33 : 67	18	33 : 67
9	12 : 88	20	28 : 72	20	25 : 75
10	54 : 46	22	50 : 50	22	42 : 58
		24	58 : 42	24	50 : 50

The threshold of intelligibility was judged to be approximately 8-9 dB C/I for the static channel, and 14-16 dB for the TU50 and HT200 channels.

There is no clear preference for the 5,9 kbit/s codec mode over the 4,75 kbit/s mode for the C/I conditions and channel types.

9.4 6,7 kbit/s Mode

As for the 5,15 kbit/s and 5,9 kbit/s modes, two listening experiments were performed for the 6,7 kbit/s mode. The first was a preference test on a three-point scale comparing the AMR 6,7 kbit/s mode to the AMR 4,75 kbit/s mode in a pair-wise fashion as described above. The second test was to establish an approximate threshold of intelligibility/acceptability for the AMR 6,7 kbit/s codec. Again, the TU5 channel was omitted.

The results are shown in table 9.4.

Table 9.4: Results of Expert Informal Listening for the 6,7 kbit/s AMR Mode – Shaded Cells Below Level of Intelligibility

Static Channel		TU50 Channel		HT200 Channel	
C/I (dB)	**6,7 : 4,75**	**C/I (dB)**	**6,7 : 4,75**	**C/I (dB)**	**6,7 : 4,75**
4	33 : 66	10	4 : 96	10	0 : 100
5	29 : 71	12	0 : 100	12	0 : 100
6	0 : 100	14	0 : 100	14	0 : 100
7	0 : 100	16	0 : 100	16	0 : 100
8	0 : 100	18	0 : 100	18	0 : 100
9	0 : 100	20	0 : 100	20	0 : 100
10	0 : 100	22	21 : 79	22	8 : 92
		24	46 : 54	24	21 : 79

The threshold of intelligibility was judged to be approximately 9-10 dB C/I for the static channel, and 16-18 dB for the TU50 and HT200 channels.

Over the full range of channel conditions, the 4,75 kbit/s mode was preferred over the 6,7 kbit/s mode.

10 Conclusions

FEC schemes were designed and evaluated for four GSM/3GPP AMR codec modes (4.75, 5.15, 5.9 and 6,7 kbit/s) as part of the TETRA system. Both objective (ITU-T Recommendation P.861 [1]) and subjective (expert listener) evaluation of the various codec modes was performed.

The 4,75 kbit/s AMR mode was shown to provide a clear benefit, in terms of quality over most of the coverage area, when compared to the TETRA codec. The other modes of the AMR codec did not demonstrate a clear improvement in quality over the 4,75 kbit/s mode for the C/Is tested.

Annex A: Software Description

Several software deliverables were produced as part of the project and these are described in this Annex; the soft-bit demodulation error files for each of the channels, generic versions of the TETRA ccoder and cdecoder routines, a utility to apply soft-bit errors to the output of ccoder and the processing script files.

A.1 Soft-Bit Error Files

These files are stored under the parent directory 'Channel_Data' in subdirectories 'Static', 'TU5', 'TU50' and 'HT200'. Static channel files have the form; sc_X_soft.bin or sc_XX_soft.bin where X or XX is the C/I used to generate the file. A similar convention is used for TU5 channel files; tu5_XX_soft.bin, TU50 channel files; tu50_XX_soft.bin and HT200 channel files; ht200_XX_soft.bin.

The files comprise 1000080 short words in big-endian (HP-UX) format representing 2315 TDMA bursts of 432 bits. The short words contain values between –127 (perfect demodulation i.e. no error) to +127 (complete corruption).

A.2 Generic 'ccoder' and 'cdecoder' Routines

These program files are stored under the parent directory 'New_FEC'. They are based very closely on the TETRA 'ccoder' and 'cdecoder' utilities that are provided as part of ETS 300 395-2 [2].

The 'ccoder' code has been made slightly more general and now accepts data in both the conventional TETRA codec format and the format generated by the 3GPP/GSM AMR Codecs. An additional option is provided to allow one of the four AMR modes to be selected. The command line is now of the form; *ccoder infile outfile [CoderType]*, where the *CoderType* is an optional integer input which defaults to the TETRA format when not present. The value of *CoderType* has the following effect; 0=TETRA, 1=AMR_475, 2=AMR_515, 3=AMR_590 and 4=AMR_670 respectively. The *infile* must be in the form expected according to CoderType; either TETRA format or AMR format.

The 'cdecoder' has been written in a similar manner; *cdecoder infile outfile [CoderType]*, and expects the same value of *CoderType* to be used as for the encoding to ensure compatible decoding is performed. This is due to the fact that the type of speech coder is not identifiable from the TETRA TDMA bit stream.

NOTE: After cdecoding, the AMR synthesis must be performed with the –rxframetype option in order for the bad frame indication to be effective.

Two *.tab files (arrays_XX.tab and const_XX.tab) define the allocation of bits for each of the AMR modes and for TETRA at compile-time where XX is the speech codec to which the data refers. Not only is the data provided for the selected FEC modes, but also for the other FEC options tried during the creation of this report. Short command script files are provided to configure the code according to the options described in the document (*create_option1*, *create_option2, create_option3* and *create_option4*) and one file configures the code according to the selected options; *create_chosen_option*.

A.3 Soft-Bit Error Injection Routine

These program files are stored under the parent directory 'Chan_Err_Inject'. A single program is required to read the TETRA TDMA format files and the soft-bit channel files and to currupt the TDMA burst data according to the soft bit files.

The routine is executed by using the following command; *inject in_file channel_file out_file*, where the files are in the expected formats. This command is independent of the speech codec being used.

A.4 Script Files

These 'C' shell files are stored under the parent directory 'Scripts'. Two sets of scripts are provided. The first set of the form '*Complete_XX_Test*' was used in order to generate the ITU-T Recommendation P.861 [1] results for the curves in this report; where *XX* is the speech codec to be used. The results are placed in the child directory 'Test_Results'.

The second set of command files is of the form; '*Complete_XX_Process*' was used to derive the speech material for the expert listening where again the *XX* is the speech codec to be used.

Two additional command files; 'Do_Every_Test' and 'Create_Listening_Data' may be used to perform all of the tests at one execution.

NOTE: These script files will not execute directly due to the absence of the source speech file (in directory 'Speech_Data') and the utility to perform the ITU-T Recommendation P.861 [1] metric calculations (in directory 'p861').

History

Document history		
V1.1.1	July 2001	Publication