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| Prepared | Phone | Date<br>2000-04-11 | Rev<br>A | Document no<br>EPL/T/TN-00:022 |
| Approved |       |                    |          | File/reference                 |

# Interpreting the Information Element “C/I”

This document primarily addresses users of TEMS Investigation.

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# 1 Introduction

## “Why is my C/I so bad?”

During your first drive test with the new TEMS Investigation release, you notice that the C/I reading drops sharply in one particular area. You know that this indicates a high level of interference on the carrier frequency, but what is the reason for this?

This document describes the most common causes of poor C/I values, and how these phenomena can be detected with the TEMS products. Also, it hints at how each of the underlying problems can be remedied.

See chapters 2–9.

## What is “interference”?

We must define what we mean by “interference” within the TEMS framework. Sometimes the meaning of the word is restricted, in that it refers exclusively to other signals from radio communication devices, and is distinguished from “noise”. Other terms are used to identify various categories of disturbances, such as “long” reflections causing problems with time dispersion, adjacent channel disturbances, etc.

We use the word “interference” here as an umbrella term for any unwanted signals, that is, any signals other than the carrier itself, and the information element “C/I” is a generalized measure of the interference level (in particular, it does *not* refer exclusively to co-channel interference).

## C/I vs. speech quality

C/I is *not* a measure of speech quality. For assessing the speech quality perceived by a human listener, the TEMS products offer another measure, the Speech Quality Index (SQI). Although it is of course generally true that severe interference problems tend to degrade speech quality, and although low C/I values typically cause SQI drops, the C/I does not give a reliable estimate of the perceived speech quality. For instance, in a cell with five carriers using frequency hopping, one of the carriers can suffer from very low C/I without the speech quality being degraded, thanks to the channel coding and interleaving employed in GSM.

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## 2 Co-channel interference

By *co-channel interference* is meant interference from other network cells using the same transmission frequency. In most environments (in fact almost anywhere except in very sparsely populated rural areas), co-channel interference is the factor that limits network capacity (the maximum number of simultaneous users). Mostly, in such cases, it is by far the most important source of interference.

In GSM, there are two main channel types: *broadcast channels* with continuous output power, and *traffic channels* whose output power is dependent on the traffic load in the cell. During cell planning, different reuse patterns are often used for the two kinds of channel, but unless the broadcast channels are put in a separate band, they may still interfere with each other.

When the interference stems from a broadcast channel, measuring the C/I is fairly straightforward thanks to the constant output power. However, if the interferer is a traffic channel, the C/I will vary according to the load on the interfering cell. This means that if, for example, you perform a drive test at night, when the amount of traffic is likely to be low, the interference situation can be totally different than during busy hour. Even functions such as downlink DTX and downlink power control can affect the interference situation.

### Using TEMS products

As stated above, co-channel interference is by far the most common cause of low C/I, and one of the tasks to be handled by future TEMS products is to identify the source of the interfering signal (the actual cell where it originates). Until such a tool is available, however, you will have to study the cell plan to identify possible interfering cells.

### Countermeasures

Some steps typically taken to reduce co-channel interference are:

- Improvement of cell planning
- Shrinking the interfering cell, e.g. by lowering its output power or tilting the antennas of its base station

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- Activating downlink DTX on the traffic channels
- Activating downlink power control on traffic channels.

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### 3 Adjacent channel interference (C/A)

A GSM mobile station is designed to demodulate a signal with a 3 dB bandwidth of approximately 170 kHz. This means that a bandpass filter is applied to the RF channel, removing signal power outside the pass band. However, this filter is not perfect: it cannot remove the unwanted signal components completely. This means that signal power can leak from adjacent carriers into the passband. Such disturbances are called *adjacent channel interference*.

Adjacent channel interference always originates from other carriers than the one the mobile is transmitting on. The GSM 05.05 specification requires that the signal transmitted from the mobile's own base station be attenuated by at least 30 dB on the nearest carriers (at +/-200 kHz) and by at least 60 dB on carriers located at +/-400 kHz.

The mobile station, in turn, is required to cope with fairly high levels of adjacent interference. It shall keep the bit error rate (BER) below  $10^{-4}$  for each of the following C/A levels (GSM 05.05):

- $C/A \geq -9$  dB at +/-200 kHz
- $C/A \geq -41$  dB at +/-400 kHz
- $C/A \geq -49$  dB at +/-600 kHz.

#### Using TEMS

C/A can be presented directly in TEMS (if enabled on the mobile station property page). C/A can also be calculated by inspecting the channel bar chart in the Frequency Scanner window; see the example below. There is therefore no need to inspect C/I in order to detect C/A problems. However, if some C/A values drop low enough, this will of course show as a deterioration in the C/I as well.

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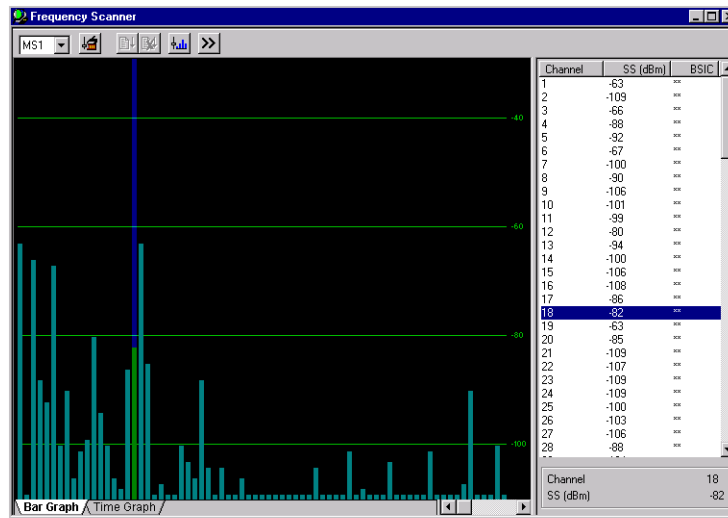


Figure 1. Detecting a C/A problem in TEMS Investigation.

In figure 1, showing the Frequency Scanner window in TEMS Investigation, the mobile is receiving on the channel with ARFCN 18 (highlighted). The adjacent channel with ARFCN 19 has a signal strength of  $-63$  dBm, while the signal strength on the mobile's own channel is a mere  $-82$  dBm. With this very high level of interference, the mobile will not be able to filter out the desired signal well enough to meet the bit error rate requirements.

### Countermeasures

The measures taken to combat excessive adjacent channel interference are the same as those directed against co-channel interference (see page 3).

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## 4 Blocking

Co-channel interference and adjacent channel interference both arise in the operator’s own network. However, an interfering signal may also originate from other sources that are beyond his control – typically from a different operator.

If a mobile station comes very close to the antenna system of a non-designated base station which is transmitting on some frequency fairly close to the mobile’s, it may happen that the transmissions from the base station completely overwhelm the mobile receiver. The typical situation where this is possible is when the base station antenna is positioned at ground level, and a mobile user passes by on the sidewalk.

As is the case with adjacent channel interference, the problem would not exist if both transmitter and receiver filters had ideal characteristics. Unfortunately, this is not so.

### Using TEMS

Blocking is conveniently detected using the Frequency Scanner bar chart.

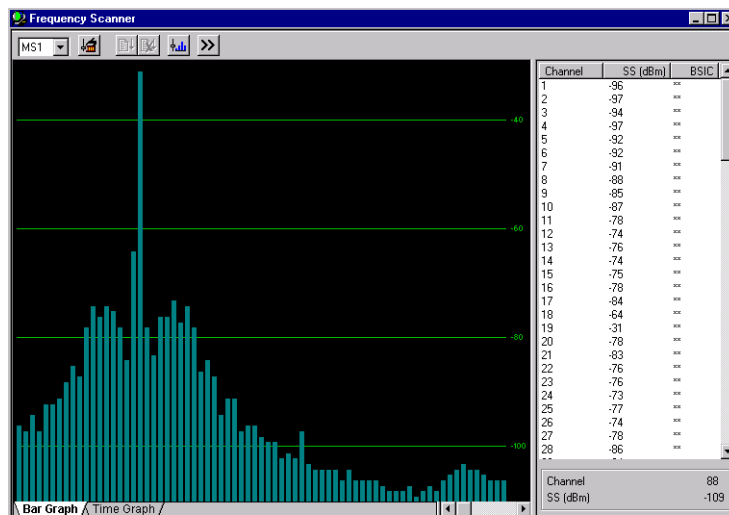


Figure 2. A typical RF spectrum with a carrier causing receiver blocking.

In figure 2, a very strong interferer is found at ARFCN 19. The signal strength reading is –31 dBm, but in this case the signal is actually even stronger, since the scanner has reached the

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high end of its measurement range. This interferer will drown ordinary transmission on all channels at a distance of up to  $\pm 15$  ARFCNs.

Blocking might appear to be an extreme phenomenon, but it is not all that uncommon for instance in certain urban environments where carriers of different operators interfere heavily with each other.

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## 5 Noise (C/N)

As was said in chapter 2, the factor most commonly limiting network capacity is the level of co-channel interference. In sufficiently sparsely populated areas, however, this ceases to apply. Here, capacity is instead limited simply by the range of the transmitters (compare walkie-talkies). In other words, the limit is set not by the amount of interference from other nearby callers, but by assorted random disturbances that are always present – i.e. what is usually termed “noise”. This concept encompasses both the thermal noise generated within the circuits of the mobile station, and external background noise from a plethora of sources, including other man-made signals so faint that they merely add up to a quasi-random disturbance.

In environments where the interference can be described as noise-like, the interference level is usually termed the C/N (carrier-to-noise) ratio or SNR (signal-to-noise ratio) instead of C/I. The noise is typically a broadband signal with stochastic variation, comparable to an AWGN (average white Gaussian noise) signal.

The level of the noise floor in a GSM mobile is determined by two parameters. The first is the thermal noise, which is dependent on the nature of the GSM RF channel (the temperature and the bandwidth of the signal). The second parameter is the amount of noise generated in the mobile station’s hardware. The noise floor is obtained from the formula

$$N_{\text{receiver}} = 10 \log(kTB) + NF_{\text{receiver}} \quad (1)$$

The  $10 \log(kTB)$  part corresponds to the thermal noise and is approximately  $-122$  dBm ( $k$  = Boltzmann’s constant,  $T$  = absolute temperature, and  $B$  = the 3 dB bandwidth of the RF channel).

The term  $NF_{\text{receiver}}$  represents the hardware noise. In order to meet the BER requirement in the GSM 05.05 specification at the reference sensitivity level ( $-104$  dBm, C/N 9 dB), the value of  $NF_{\text{receiver}}$  must not exceed

$$NF_{\text{receiver max}} = -104 - 9 - (-122) = 9 \text{ dB} \quad (2)$$

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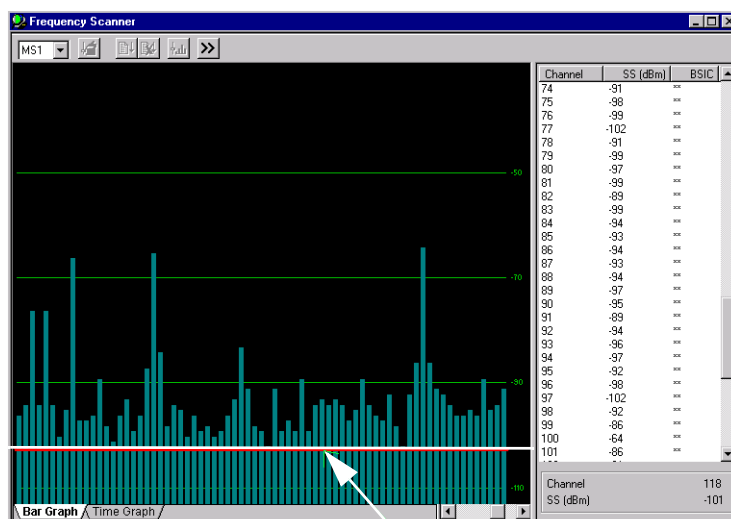
This means that the noise floor in a GSM mobile lies at approximately  $-113$  dBm (i.e.  $-122$  dBm + 9 dB according to eq. (1) above). However, in practice, a certain margin is required because of temperature variation, aging of the RF components in the receiver, etc. This means that in actuality the noise floor will be 2-3 dB lower than  $-113$  dBm (the exact value being manufacturer dependent).

**Using TEMS**

When there is a noise problem, the signal strength is often very low (say, below  $-100$  dBm) while C/I is bad.

Of course, if the background noise increases in intensity, the receiving conditions deteriorate. The image below shows a situation where the noise floor has risen from the expected level (according to (2)) to almost  $-100$  dBm.

Note that in current versions of the TEMS products, the lower range limit for presented signal strength is  $-110$  dBm.



Noise floor at approx.  $-100$  dBm

Figure 3. Example of a broadband signal raising the noise floor.

**Countermeasures**

If the noise problem exists only on the downlink, it can be remedied simply by increasing the base station output power, provided a) that the equipment is not already operating at

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maximum power, and b) that the expanded cell can cope with the increased amount of traffic. If these conditions are not both fulfilled, improving coverage requires introducing new cells.

In the example in figure 3, the source of the broadband signal has to be identified and eliminated.

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## 6 Intermodulation products

Intermodulation (IM) products are unwanted disturbances that may arise when several signals with different frequencies are mixed. This mixing can occur in nonlinear components in both transmitters and receivers, and also in various metal objects encountered in the air interface (wire fences, railings, etc.). In the latter case, signals from different cellular systems may be mixed, and they might interfere with one another even if they belong to different frequency bands.

The IM products are found at frequencies equal to linear combinations of the original frequencies, i.e.  $2f_1 - f_2$ ,  $2f_2 - f_1$ ,  $3f_2 - 2f_1$ , etc. IM products containing  $n$  terms of the form  $a_i f_i$  are said to be of order  $n$ . The figure below shows some IM products generated by two signals with frequencies  $f_1$  and  $f_2$ :

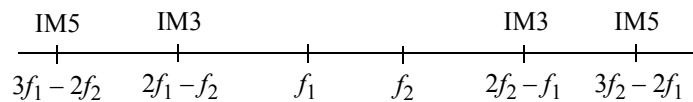


Figure 4. Example of intermodulation products.

The strength of the IM products declines with higher order. In GSM, it is those of order 3 (and in part those of order 5) that cause problems; higher-order IM products need not be considered. A set of three frequencies  $f_1 < f_2 < f_3$  could create the following potentially harmful IM products of order 3:  $2f_1 - f_2$ ,  $2f_1 - f_3$ ,  $f_1 + f_2 - f_3$ ,  $2f_2 - f_3$ .

Note that IM products do not disturb the signals that give rise to them, since they are located at totally different frequencies. They may, however, disturb other signals. Therefore, when choosing the downlink frequencies to be used in a cell, one must ensure that no IM products coincide with some uplink frequency in the cell. Obviously, the complexity of avoiding such problems grows rapidly with the number of frequencies involved.

### Using TEMS

IM products can be detected in TEMS by using the scanning function to study the radio frequency spectrum. However, this is not an easy task and requires RF experience. One approach is

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to use the fact that if the input signal is attenuated, an IM product will be attenuated more than the corresponding carriers. For example, if the carriers generating IM3 products are attenuated 10 dB, the corresponding IM3 product will be attenuated 30 dB.

**Countermeasures**

Frequency planning: One simply has to make sure that unfortunate combinations of frequencies are not used.

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## 7 Time dispersion (C/R)

If the transmitted radio wave is reflected by large objects in the service area, the mobile station will receive multiple copies of the wave at slightly different times. The bit stream from the direct wave may arrive a number of bit times earlier than the identical reflected bits (intersymbol interference). This phenomenon is known as *time dispersion*.

Time dispersion complicates the task of the receiver. However, if the reflections are not too much delayed, it is possible, simply put, to separate the different copies of the signal from each other and improve the reconstruction of the transmitted signal by utilizing the information content in all the copies. In other words, the receiver can profit by the time dispersion phenomenon. It should be noted that, at least in urban areas, receiving the direct (line-of-sight) wave is actually fairly unusual, so that the receiver is *dependent* on picking up reflections.

The GSM specification requires that the system should be able to handle a time dispersion of up to 15  $\mu$ s, corresponding to a path difference of 4.5 km. This means that it shall be possible to handle a set of signal copies arriving within a 15  $\mu$ s window (including or not including the direct wave) as independent sources of information for the reconstruction of the original. For this to be possible, reflections delayed longer than 15  $\mu$ s must be sufficiently weak. A GSM receiver must, according to the 05.05 specification, be able to handle a level of interference where the total power of all reflections delayed more than 15  $\mu$ s is at least 9 dB weaker than the power of the signals within the 15  $\mu$ s window. In other words, assuming no other interference, the C/R ratio must be at least 9 dB.

Typical causes of severe and thus problematic time dispersion are

- large buildings with reflecting surfaces (metal, glass)
- mountain ranges
- lakes with steeps or densely built-up shores

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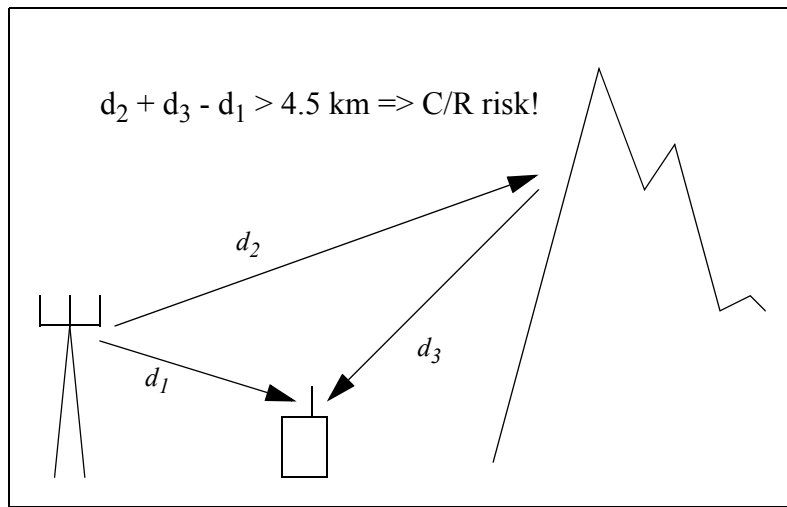


Figure 5. Time dispersion.

**Using TEMS**

Today, there is no way of measuring time dispersion in the TEMS products. This is one of the tasks that are under investigation for the future product portfolio.

**Countermeasures**

Cell planning.

Antenna direction.

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## 8 Receiver saturation

If the signal strength from the serving cell becomes very high (say,  $> -30$  dBm), it can be seen that the C/I goes down. This is due to the fact that the A/D converter in the mobile has reached the limit of its dynamic range; it is said to be *saturated*. (It can also be remarked that the mobile cannot measure higher signal strengths than approx.  $-30$  dBm.)

As might be expected, receiver saturation is frequent in the immediate vicinity of base stations with a high output power (typically found in rural areas). The risk of encountering this problem in urban environments is smaller, since base stations in such places use a much lower power and are designed to allow mobiles to come much closer without upsetting their operation.

### Countermeasures

There is in fact not much that can be done about this problem, since it is an unavoidable consequence of cellular system design.

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## 9 Amplitude Modulation of LNA Operating Point

The GSM 05.05 specification states requirements on what is called “AM suppression”. These are necessary to neutralize a special kind of disturbance which is caused by an intermittent interfering signal.

In a GSM receiver, there is an amplifier called the LNA (low noise amplifier), which is located after the antenna and the first RF bandpass filter. The LNA is designed to work at an optimal operating point, which is adjusted continuously. There is, however, a limit to the speed at which the operating point can be adjusted. If a very strong interferer (even on an adjacent carrier) suddenly appears in the middle of a burst from the serving cell, the control of the operating point cannot keep up, so that the operating point temporarily becomes suboptimal (it is said to be amplitude modulated). Interference of this kind usually originates from a different base station whose output power is subject to abrupt changes.

Unless it is kept in check, this sort of non-ideal amplifier behavior may have the effect of degrading performance in terms of bit error rate. However, the requirements in GSM 05.05 are such that the control of the operating point in GSM receivers is good enough to eliminate this problem in practice.