# DVB-T — C/N values for portable single and diversity reception

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**It has been shown that the minimum *C/N* values for good-quality portable DVB-T reception in a static Rayleigh channel – as given in the ETSI DVB-T standard – are too low. With this in mind, the IRT carried out extensive laboratory measurements on DVB-T reception (both single and diversity) at 610 MHz – using a number of different modulation schemes and code rates.**

**Resulting from these measurements, a new set of *C/N* values for portable urban reception is proposed.**

Field measurements have shown that the minimum *C/N* values for good-quality portable DVB-T reception in a static Rayleigh channel – as given in the ETSI DVB-T Standard [1] – are too low. The *C/N* values that are necessary for good portable **single** and **diversity** DVB-T reception were therefore measured in the laboratory at 610 MHz, for the 8k modulation schemes QPSK, 16-QAM and 64-QAM – at code rates of 1/2, 2/3 and 3/4 and with a guard interval of 1/8. The measurements were carried out in both a static Rayleigh channel and a simulated, realistic, time-variable, portable reception channel in an urban area.

The multipath field (the usual field in portable reception) is never static. The antenna output power fluctuates even if the antenna is fixed, because the field strength is changing continuously. A DVB-T receiver is less sensitive in a time-variable channel, compared to a static channel, and therefore the minimum *C/N* values are higher than in [1].

## *C/N* in a static Rayleigh channel

### *Measurement method*

The DVB-T signal was generated by a Rohde & Schwarz signal generator (SFQ) which includes a 12-path channel simulator. After mixing in a specified amount of noise, the composite signal was fed to a DVB-T receiver. The receiver used was based on the DiBcom chip, DIB 3000-M, and can be set to receive DVB-T in single or diversity mode (which requires two receiving antennas). The Bit Error Rate (BER) of the DVB-T signal was measured by the DiBcom receiver and displayed by its control software.

The standard SFQ transmitter – Rayleigh multipath channel, type RL 12 ANX B – was used for a first set of measurements in a simulated static Rayleigh channel. The settings for the path loss, the delay, the phase and the profile of the 12 paths used to simulate the channel are shown in *Table 1*.

**Table 1**
**12-path static Rayleigh channel simulation, RL12 ANX B, used for *C/N* measurements**

| Path loss (dB) | Delay (µs) | Phase (deg.) | Profile |
|---|---|---|---|
| 7.9 | 0.5 | 336.0 | const. phase |
| 10.5 | 2.75 | 127.0 | const. phase |
| 11.8 | 0.6 | 215.3 | const. phase |
| 14.8 | 3.3 | 330.9 | const. phase |
| 8.0 | 1.95 | 8.8 | const. phase |
| 10.7 | 0.45 | 339.7 | const. phase |
| 9.2 | 3.25 | 174.9 | const. phase |
| 11.7 | 0.85 | 36.0 | const. phase |
| 13.0 | 0.05 | 122.0 | const. phase |
| 12.5 | 0.9 | 210.0 | const. phase |
| 13.2 | 0.65 | 191.0 | const. phase |
| 11.8 | 1.35 | 22.6 | const. phase |

*Table 2* shows the Annex B profile given in the DVB-T standard, ETSI EN 300 744 [1]. Only the 12 paths with the highest power (indicated by yellow rows in *Table 2*) are included – with minor changes – in the RL12 ANX B profile *(Table 1)*. The two profiles are almost equivalent, as the eight missing paths (white-coloured rows) are very low powered.

**Table 2**
**20-path static Rayleigh profile in Annex B of the DVB-T standard, ETSI EN 300 744**

| i | Path loss (dB) | Delay (µs) | Phase (deg.) |
|---|---|---|---|
| 1 | 24.8 | 1.0 | 278.2 |
| 2 | 15.0 | 5.42 | 195.9 |
| 3 | 7.8 | 0.52 | 336.0 |
| 4 | 10.4 | 2.75 | 127.0 |
| 5 | 11.7 | 0.6 | 215.3 |
| 6 | 24.2 | 1.02 | 311.1 |
| 7 | 16.5 | 0.14 | 226.4 |
| 8 | 25.8 | 0.15 | 62.7 |
| 9 | 14.7 | 3.32 | 330.9 |
| 10 | 7.9 | 1.93 | 8.8 |
| 11 | 10.6 | 0.43 | 339.7 |
| 12 | 9.1 | 3.23 | 174.9 |
| 13 | 11.6 | 0.85 | 36.0 |
| 14 | 12.9 | 0.07 | 122.0 |
| 15 | 15.3 | 0.2 | 63.0 |
| 16 | 16.5 | 0.19 | 198.4 |
| 17 | 12.4 | 0.92 | 210.0 |
| 18 | 18.7 | 1.38 | 162.4 |
| 19 | 13.1 | 0.64 | 191.0 |
| 20 | 11.7 | 1.37 | 22.6 |

**Table 3**
**The first seven phase sets (in degrees) used instead of the values given in *Table 1*, column 4 for *C/N* measurements in a static Rayleigh channel**

| Path \ Set | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| 1 | 207.3 | 235.8 | 176.1 | 25.1 | 268.4 | 189.7 | 255.5 |
| 2 | 329.4 | 308.0 | 262.1 | 3.1 | 155.7 | 69.8 | 256.9 |
| 3 | 201.2 | 63.0 | 149.8 | 164.2 | 32.9 | 165.9 | 228.7 |
| 4 | 283.6 | 274.9 | 53.5 | 301.2 | 134.6 | 129.7 | 175.3 |
| 5 | 356.8 | 327.6 | 114.1 | 24.4 | 289.7 | 232.8 | 76.8 |
| 6 | 220.1 | 296.3 | 254.6 | 174.1 | 146.1 | 32.2 | 42.0 |
| 7 | 5.6 | 344.9 | 130.0 | 355.9 | 158.9 | 316.0 | 95.8 |
| 8 | 294.9 | 172.9 | 276.4 | 136.4 | 260.6 | 167.0 | 135.1 |
| 9 | 28.7 | 314.3 | 298.9 | 171.0 | 165.6 | 292.9 | 154.1 |
| 10 | 313.6 | 172.7 | 83.6 | 329.5 | 64.9 | 74.0 | 252.6 |
| 11 | 162.4 | 327.9 | 358.5 | 310.7 | 216.8 | 148.9 | 107.2 |
| 12 | 103.9 | 32.5 | 194.0 | 168.6 | 238.6 | 81.6 | 341.7 |

The relative power sum of all paths in *Table 1*, assuming they are uncorrelated, is the sum of the squared linear path losses and has unity value ("1").

In a static Rayleigh channel, the phases of the paths have random values. The constant phase of every path in column 4 of *Table 1* was randomly chosen. Therefore this phase set is just one of an infinite number of possible phase combinations.

The vector sum of the 12 path vectors depends on the values of the constant phases. For different sets of the 12 randomly-chosen phases, the power of the sum vector is *normally* distributed with a mean value of "one".

Fifty random phase sets were randomly generated, covering the range from 0 to 360°. The first seven sets are shown in *Table 3*. For every phase set, the resulting generator output power and the minimum *C/N* for good reception were measured.

Let us suppose that, in a part of the coverage area, the multipath signals arriving from all directions have 12 components with the path losses and delays given in *Table 1*. If we consider an elementary homogenous terrain area of approx. 100m x 100m, which is a typical size used for coverage predictions, the power ***C*** entering from all directions into this elementary area is the power sum of the 12 paths.

At every point in the elementary area, the phases of the 12 paths will have different values. At a point *i*, where the path phases have the values of the phase-set *i* (one of the seven sets in *Table 3* and 43 more), the vector sum of the 12 path vectors has the power $P_i$ which, in most cases, is either higher or lower than ***C***. However, the mean and median value of all $P_i$ values in the elementary area is nevertheless ***C***.

The signal power setting at the SFQ generator output corresponds to ***C*** even if, for a certain phase set *i*, the output power is $P_i$. For every phase set *i* the noise power $N_i$ was adjusted by changing the *C/N* setting of the gen-

## Abbreviations

| | |
|---|---|
| **16-QAM** | 16-state Quadrature Amplitude Modulation |
| **64-QAM** | 64-state Quadrature Amplitude Modulation |
| **BER** | Bit-Error Ratio |
| **C/N** | Carrier-to-Noise ratio |
| **DVB** | Digital Video Broadcasting |
| **DVB-T** | DVB - Terrestrial |
| **$ESR_5$** | Erroneous Second Ratio, 5% |
| **ETS** | European Telecommunication Standard |
| **ETSI** | European Telecommunication Standards Institute |
| **QEF** | Quasi-Error-Free |
| **QPSK** | Quadrature (Quaternary) Phase-Shift Keying |

erator to satisfy a specific transmission quality criterion. In that way, for every phase set *i*, the corresponding $C/N_i$ was measured. The values found were distributed in a range around a mean value.

The two transmission quality criteria used were (i) "quasi-error-free" (QEF**)** and (ii) "erroneous second ratio 5%" ($ESR_5$). QEF corresponds to a BER of $2*10^{-4}$ after the Viterbi decoder, and $ESR_5$ means that there is a maximum of one erroneous second in 20 seconds, for good reception. Measurements have shown that, in a static Rayleigh channel, the $ESR_5$ criterion is fulfilled at a BER of $2*10^{-3}$.

## Measurement results

The generator output power is the power of the vector sum of the 12 path vectors and depends on the vector phase settings. The power values measured for the 50 phase sets used were classified to find the probability distribution.

The cumulative *frequency* distribution of the measured 12-path signal power values is shown in *Fig. 1* in a **probability diagram**, i.e. a diagram where the y-axis is non-linear in such a way that the cumulative distribution of a normally distributed variable is a straight line. The slope of the line depends on the standard deviation.

The power cumulative frequency distribution in *Fig. 1* is almost linear, which means that the power values probability distribution is of the type "normal" (i.e. Gaussian). The distribution standard deviation is 0.85 dB.

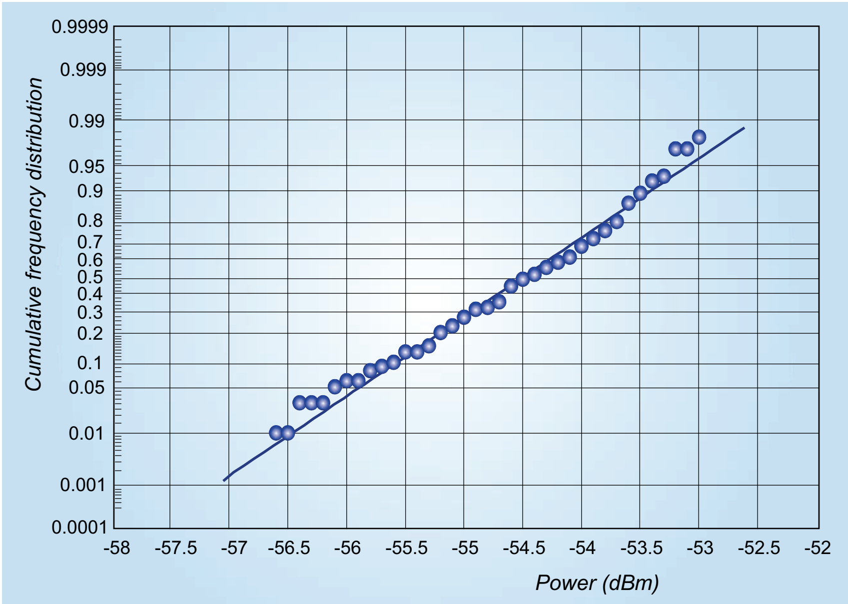


**Figure 1**
**Cumulative frequency distribution of the sum power values of the 12-path Rayleigh channel signal (RL 12 ANX B ) with 50 sets of random phase values, used for the static *C/N* measurements**
**(median value = –54.5 dB, standard deviation = 0.85 dB)**

For every one of the 50 phase sets, the minimum *C/N* value necessary for good reception was measured. The cumulative *probability* distributions of the *C/N* values measured for the mode 16-QAM 2/3, using the quality criteria QEF and $ESR_5$ are depicted in *Fig. 2*. The straight lines are the "fitted" normal distributions. In the legend, the values in parenthesis are the median value and the standard deviation, both in dB.

The minimum *C/N* value which satisfies the QEF quality criterion is 1.4 dB higher than the value necessary to satisfy the $ESR_5$ criterion.

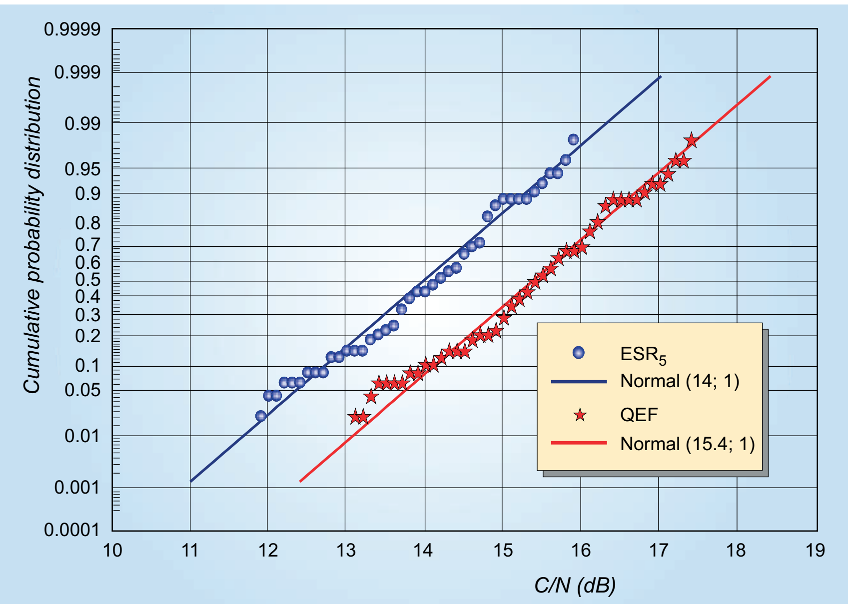


**Figure 2**
**Cumulative probability distribution of the *C/N* values at 610 MHz, mode 16-QAM 2/3 in the RL 12 ANX B static Rayleigh channel, using quality criteria QEF and $ESR_5$**

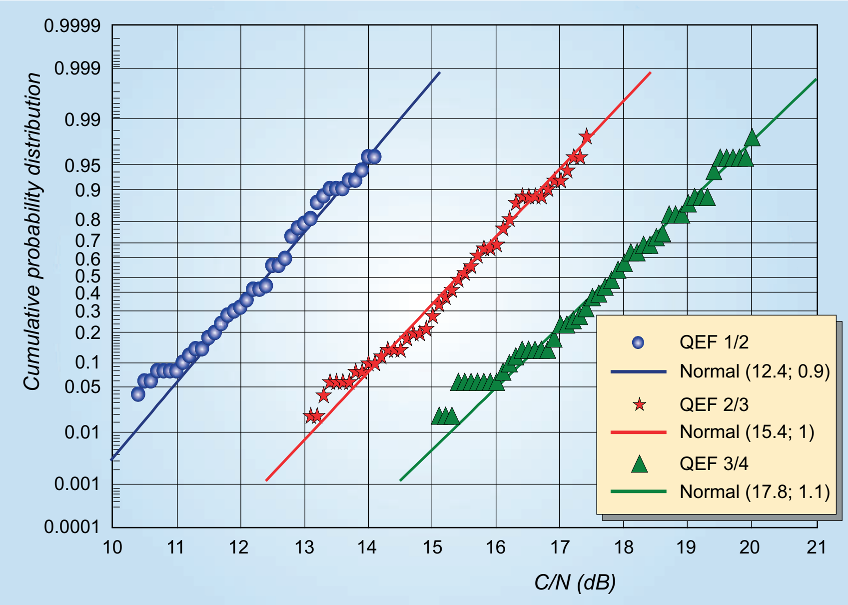


**Figure 3**
**Cumulative probability distribution of the *C/N* values at 610 MHz, mode 16-QAM 1/2, 2/3 and 3/4 in the RL 12 ANX B static Rayleigh channel, using quality criterion QEF**

The QEF criterion is more demanding.

For comparison, *Fig. 3* shows the *C/N* cumulative probability distributions measured in the static Rayleigh channel using 16-QAM at the code rates 1/2, 2/3 and 3/4, and for the QEF quality criterion.

At the highest code rate (3/4), the median *C/N* is also the highest, at 17.8 dB. Increasing the forward error protection by decreasing the code rate to 2/3 reduces the *C/N* by 2.4 dB to 15.4 dB. At the lowest code rate (1/2), the *C/N* is further reduced by 3 dB to 12.4 dB. The standard deviation, however, stays almost constant at each code rate (with a value of about 1 dB).

The cumulative frequency distributions of *C/N* in *Fig. 2* and *Fig. 3* (diagrams with a "probability" vertical axis) are quite linear, indicating that the *C/N* value distributions are of the type *normal*. The normal probability distribution is completely defined by the median value and the standard deviation. The parameters of the *C/N* probability distributions in *Fig. 3* and for the other modes measured are given in *Table 4*.

The *C/N* values given in *Table 4* were measured with a specific receiver. However, it would be more practical to have values that are receiver-independent. For the profile with the phase set shown in *Table 1*, the *C/N* values were calculated using an analytical simulation of the transmission. The difference between the calculated *C/N* values given in the ETSI standard [1] and the measured values is the **receiver implementation loss**. If we subtract the receiver implementation loss from the measured *C/N* values in *Table 4* we get values which are receiver-independent.

**Table 4**
**Parameters of the normal probability distribution of the measured *C/N* values in a static Rayleigh channel at 610 MHz (DiBcom receiver): Quality criterion = QEF**

| | | *C/N* | |
|---|---|---|---|
| **Modulation** | **Code rate** | **Median value (dB)** | **Standard dev. (dB)** |
| **QPSK** | 1/2 | 6.9 | 1.0 |
| **QPSK** | 2/3 | 9.9 | 1.0 |
| **QPSK** | 3/4 | 12.0 | 1.0 |
| **16-QAM** | 1/2 | 12.4 | 0.9 |
| **16-QAM** | 2/3 | 15.4 | 1.0 |
| **16-QAM** | 3/4 | 17.8 | 1.1 |
| **64-QAM** | 1/2 | 17.0 | 0.9 |
| **64-QAM** | 2/3 | 20.9 | 1.0 |
| **64-QAM** | 3/4 | 23.6 | 1.0 |

**Table 5**
**Implementation loss for all modes measured with the static Rayleigh profile RL12 ANX B (ETSI)**

| Modulation | Code rate | *C/N* for quasi-ETSI profile | | Implementation loss of receiver (dB) |
|---|---|---|---|---|
| | | ETSI values (dB) | Measured values (dB) | |
| QPSK | 1/2 | 5.4 | 6.0 | 0.6 |
| QPSK | 2/3 | 8.4 | 9.0 | 0.6 |
| QPSK | 3/4 | 10.7 | 11.3 | 0.6 |
| 16-QAM | 1/2 | 11.2 | 11.5 | 0.3 |
| 16-QAM | 2/3 | 14.2 | 14.6 | 0.4 |
| 16-QAM | 3/4 | 16.7 | 17.0 | 0.3 |
| 64-QAM | 1/2 | 16.0 | 16.0 | 0.0 |
| 64-QAM | 2/3 | 19.3 | 20.0 | 0.7 |
| 64-QAM | 3/4 | 21.7 | 22.6 | 0.9 |

The *C/N* value measured with the standard SFQ profile – RL12 ANX B (quasi ETSI profile) with the original phase set (given in *Table 1*) and the QEF criterion – is 14.6 dB for the mode 16-QAM 2/3. The calculated value given for the same profile in the ETSI Standard [1] is *C/N* = 14.2 dB. This means that the DiBcom-chip receiver used has an implementation loss of 0.4 dB in the case of 16-QAM 2/3.

The same calculations were carried out for the other modes. The implementation losses for all modes measured with the static Rayleigh profile, RL12 ANX B, are given in *Table 5***.**

The receiver implementation loss values are significantly lower than the 3 dB value proposed in the Chester agreement [2] for coverage prognosis. The reduction is due to technological improvements in the design of decoder chips.

The *C/N* values in *Table 4* were reduced by the implementation loss given in *Table 5* and the results are shown in *Table 6* as receiver-independent values.

**Table 6**
**Parameters of the receiver-independent *C/N* normal probability distribution in a static Rayleigh-channel at 610 MHz: Quality criterion = QEF**

| Modulation | Code rate | *C/N* | |
|---|---|---|---|
| | | Median value (dB) | Standard dev. (dB) |
| QPSK | 1/2 | 6.3 | 1.0 |
| QPSK | 2/3 | 9.3 | 1.0 |
| QPSK | 3/4 | 11.4 | 1.0 |
| 16-QAM | 1/2 | 12.1 | 0.9 |
| 16-QAM | 2/3 | 15.0 | 1.0 |
| 16-QAM | 3/4 | 17.5 | 1.1 |
| 64-QAM | 1/2 | 17.0 | 0.9 |
| 64-QAM | 2/3 | 20.2 | 1.0 |
| 64-QAM | 3/4 | 22.7 | 1.0 |

The 50 random phase sets used in the measurements correspond to 50 different fixed points in an elementary area, where the path phases depend on the relative differences in the path lengths. For that reason the distributions in *Fig. 2* and *Fig. 3* can be considered as the *C/N* location cumulative probability distributions over the elementary area.

If we consider that the portable DVB-T channel is static, which is not normally the case, in order to have good reception over 99% of an elementary area, the *C/N* should be the median value plus 2.33 times the standard deviation. A "99% good reception" target might seem too demanding, but one must keep in mind that the *C/N* location distribution changes with the frequency. The probability of good reception of two channels at one location is therefore $(0.99)^2 = 0.98$ (98%) and the probability of good reception for five channels at one location is $(0.99)^5 = 0.95$ (95 %).

If we assume that a receiver with an implementation loss of 3 dB is used, then for a 99% probability of good reception in the elementary area on one frequency (one channel), the minimum *C/N* has the values given in *Table 7*.

By comparing the *C/N* = 20.3 dB value for 16-QAM 2/3 in *Table 7* with the 17.2 dB figure given in the Chester agreement [2], one finds an increase of 3.1 dB. This *C/N* – or received power increase relative to values given previously – is necessary for good DVB-T reception in a static Rayleigh channel, in conformity with the QEF criterion over 99% of the area, assuming a receiver implementation loss of 3 dB.

**Table 7**
***C/N*** **values required for good portable reception in a static Rayleigh channel, in conformity with the QEF criterion for 99% of the area, for a receiver with an implementation loss of 3 dB**

| Modulation | Code rate | *C/N* (dB) |
|---|---|---|
| QPSK | 1/2 | 11.6 |
| QPSK | 2/3 | 14.6 |
| QPSK | 3/4 | 16.7 |
| 16-QAM | 1/2 | 17.2 |
| 16-QAM | 2/3 | 20.3 |
| 16-QAM | 3/4 | 23.1 |
| 64-QAM | 1/2 | 22.1 |
| 64-QAM | 2/3 | 25.5 |
| 64-QAM | 3/4 | 28.0 |

# *C/N* in a portable (time-varying) Rayleigh channel

## *Measurement method*

The multipath environment associated with portable DVB-T reception is almost never static in real life – the received power is changing continuously with time, even if the receiving antenna is not moved. At the antenna of a portable receiver, all possible phase value combinations will eventually take place. This means that the *C/N* value for 16-QAM 2/3 will eventually take all the values given in *Fig. 2*. The normally-distributed *C/N* **location** variation changes in this case (fixed reception point) to a **time** variation, with *time ratio* on the vertical axis.

The receiver performance is better in a static field than in a time-varying field. The *C/N* values measured in the static Rayleigh channel are too optimistic. They were not confirmed by measurements in portable channels. For that reason a new set of *C/N* measurements was done in a slowly changing Rayleigh channel – a mobile "typical-urban" channel. This channel is similar to the portable reception channel, where the receiving antenna is mostly stationary, but the field is moving slowly.

The standard SFQ simulator channel profile called "TU12 path" was used for the measurements, at a very low moving velocity of 0.4 km/h. At 610 MHz, this velocity produces a maximum Doppler frequency of 0.2 Hz. The losses, the delay, the speed and the profile of the 12 paths in the "TU12 path" channel profile are given in *Table 8*.

The measurement set-up consisted mainly of a DVB-T generator, a receiver and an MPEG-2 analyzer. The DVB-T signal in the generator was passed to the internal 12-path fading simulator. At its output, the signal was combined with noise in order to get a defined *C/N* value. The resulting signal+noise sum was then handed over to the DVB-T receiver.

The quality criterion used in the measurements made on the time-varying portable channel was $ESR_5$, which we encountered earlier in this article. The transport stream decoded by the receiver was fed to an MPEG-2 decoder and analyzer, where the transmission errors were detected (synchronization loss and transport-stream error flag-set) and this information was recorded on a notebook PC.

The QEF quality criterion cannot be used, because the BER measurements are not meaningful. The bit errors occur in heavy bursts and, as there is no time interleaving, the error effect cannot be spread over a longer time period. Even if the mean BER is $2*10^{-4}$, there are significant uncorrected errors in the decoded signal from time to time, when error bursts happen.

The DVB-T generator's internal noise level is adjustable by setting the *C/N* value. For every *C/N* setting, the transport stream errors were logged for one hour. After that the error log was analyzed in accordance with the

**Table 8**
**"Typical Urban (TU) 12-path" profile at 0.4 km/h used to simulate portable reception**

| Path linear | Path loss (dB) | Delay (µs) | Speed (km/h) | Profile |
|---|---|---|---|---|
| **0.63** | 4 | 0.0 | 0.4 | Rayleigh |
| **0.71** | 3 | 0.2 | 0.4 | Rayleigh |
| **1.00** | 0 | 0.4 | 0.4 | Rayleigh |
| **0.79** | 2 | 0.6 | 0.4 | Rayleigh |
| **0.71** | 3 | 0.8 | 0.4 | Rayleigh |
| **0.56** | 5 | 1.2 | 0.4 | Rayleigh |
| **0.45** | 7 | 1.4 | 0.4 | Rayleigh |
| **0.56** | 5 | 1.8 | 0.4 | Rayleigh |
| **0.50** | 6 | 2.4 | 0.4 | Rayleigh |
| **0.35** | 9 | 3.1 | 0.4 | Rayleigh |
| **0.28** | 11 | 3.2 | 0.4 | Rayleigh |
| **0.32** | 10 | 5.0 | 0.4 | Rayleigh |

$ESR_5$ criterion, which states that the transmission quality is "good" over a 20-second time interval if, during this interval, there is no more than one second of errors. The 3600 seconds of the 1-hour measurement cycle were analyzed in 20-second intervals, and every interval was marked as either "good" or "bad".

The ratio < *intervals with good reception* / *all intervals* > within the measurement hour was then calculated.

The measurements were done for five to six different *C/N* values, in order to obtain the points with ratios between 0.01 to 0.99. The value pairs, *C/N* and "time ratio of good reception", were then represented in a probability diagram.

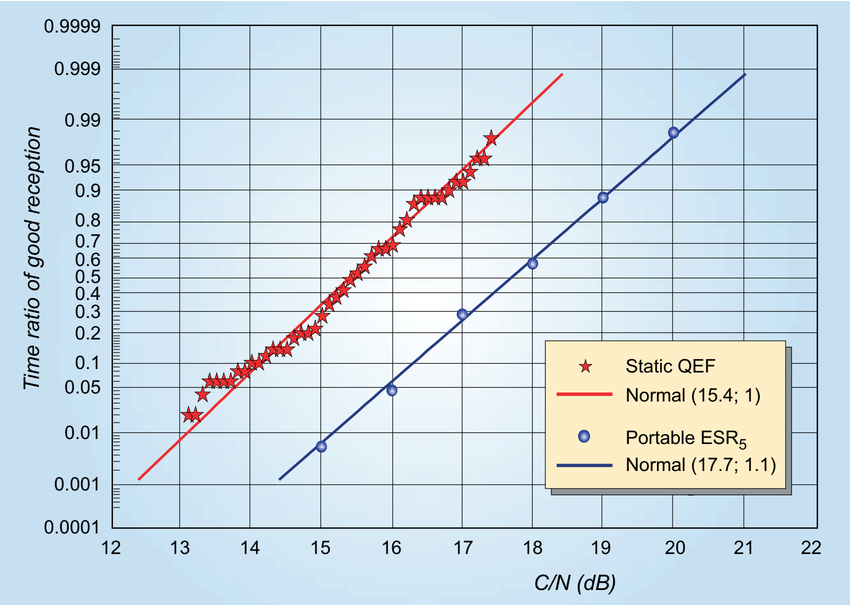


**Figure 4**
**Time ratio of good reception versus *C/N* in a time-varying portable channel, with quality criterion $ESR_5$, along with the cumulative probability distribution of the *C/N* values in a static Rayleigh channel for the quality criterion QEF and mode 16-QAM 2/3 at 610 MHz**

## *Measurement results*

The time ratios of good reception measured for different *C/N* values are marked in *Fig. 4* as blue points. With increasing *C/N* the time ratio of good reception increases too. The diagram is equivalent to a cumulative probability distribution of *C/N* for good reception according to the $ESR_5$ criterion. The blue line through the points is the cumulative probability distribution of a normal distribution with a 17.7 dB median value and a standard deviation of 1.1 dB.

The minimum *C/N* values for good DVB-T reception in the simulated time-varying portable channel are therefore normally distributed. The *C/N* distribution in a static Rayleigh

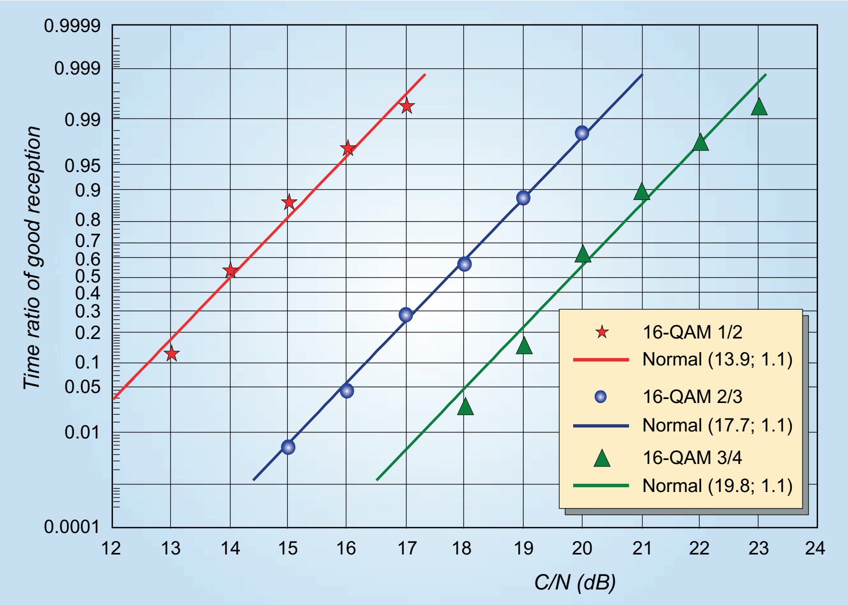


**Figure 5**
**Time ratio of good reception versus *C/N* at 610 MHz for mode 16-QAM at code rates of 1/2, 2/3 and 3/4 in a time-varying portable channel: Quality criteria = $ESR_5$**

channel (taken from *Fig. 2*) has been included in *Fig. 4* (shown as red stars) to underline the difference between the time-varying and static portable channels.

The median *C/N* value for the time-varying portable channel, measured using the quality criterion $ESR_5$, is 2.3 dB higher than the corresponding value for the static Rayleigh channel. The standard deviation in the time-varying channel is 10% higher than in the static Rayleigh channel.

In *Fig. 5* the time ratio of good reception versus *C/N* in the simulated time-varying portable channel is shown for 16-QAM at code rates of 1/2, 2/3 and 3/4, for easy comparison. The standard deviations of the probability distributions do not change with the code rate.

Reducing the code rate from 3/4 to 2/3 allows a *C/N* or power reduction of 2.1 dB for the same transmission quality. Reducing the code rate further (to 1/2) allows a supplementary *C/N* or power reduction of 3.8 dB.

The parameters of the portable *C/N* time probability distributions shown in *Fig. 5* are listed in *Table 9*.

The *C/N* values given in *Table 9* for good reception in conformity with the $ESR_5$ criterion are receiver-dependent. To get receiver-independent values, the receiver-dependent implementation loss should be subtracted. However, implementation loss values in a portable channel are not available. If we assume that the static values in *Table 5* are valid for the portable channel too, we get the parameters of the *C/N* probability distributions shown in *Table 10*.

**Table 9**
**Parameters of the time probability distributions of the measured *C/N* values in a time-varying portable channel at 610 MHz (DiBcom receiver): Quality criteria = $ESR_5$**

| | | *C/N* | |
|---|---|---|---|
| **Modulation** | **Code rate** | **Median value (dB)** | **Standard dev. (dB)** |
| **QPSK** | 1/2 | 8.8 | 1.0 |
| **QPSK** | 2/3 | 12.0 | 1.0 |
| **QPSK** | 3/4 | 14.0 | 1.0 |
| **16-QAM** | 1/2 | 13.9 | 1.1 |
| **16-QAM** | 2/3 | 17.7 | 1.1 |
| **16-QAM** | 3/4 | 19.8 | 1.1 |
| **64-QAM** | 1/2 | 18.5 | 1.1 |
| **64-QAM** | 2/3 | 22.7 | 1.0 |
| **64-QAM** | 3/4 | 24.8 | 1.1 |

**Table 10**
**Parameters of the receiver-independent *C/N* normal probability distributions in a time-varying portable channel at 610 MHz: Quality criteria = $ESR_5$**

| | | *C/N* | |
|---|---|---|---|
| **Modulation** | **Code rate** | **Median value (dB)** | **Standard dev. (dB)** |
| **QPSK** | 1/2 | 8.2 | 1.0 |
| **QPSK** | 2/3 | 11.4 | 1.0 |
| **QPSK** | 3/4 | 13.4 | 1.0 |
| **16-QAM** | 1/2 | 13.6 | 1.1 |
| **16-QAM** | 2/3 | 17.3 | 1.1 |
| **16-QAM** | 3/4 | 19.5 | 1.1 |
| **64-QAM** | 1/2 | 18.5 | 1.1 |
| **64-QAM** | 2/3 | 22.0 | 1.0 |
| **64-QAM** | 3/4 | 23.9 | 1.1 |

For good reception 99% of the time in conformity with the $ESR_5$ criterion, the *C/N* value should be the median value plus 2.33 times the standard deviation *(see the earlier section on the static Rayleigh channel)*. If we consider a receiver with an implementation loss of 3 dB, the minimum *C/N* for a 99% probability of good reception takes relatively high values.

Let us consider the fact that technological progress has reduced the implementation loss below 1 dB. *Table 11* shows the *C/N* values for good portable reception 99% of time, in conformity with the $ESR_5$ criterion, for a receiver with an implementation loss of 1 dB.

When calculating coverage areas for portable DVB-T reception of 16-QAM 2/3, we should allow an increase of 3.7 dB in the *C/N* value – from the 17.2 dB value given in the Chester agreement [2] to the 20.9 dB value given in *Table 11*. For the other modulation modes too, the values given in *Table 11* should be used instead of the values given in [2]. The *C/N* values given in *Table 11* are suitable for up-to-date receivers with an implementation loss of no more than 1 dB.

**Table 11**
***C/N* values required for good portable reception 99% of the time in conformity with the $ESR_5$ criterion, for a receiver with an implementation loss of 1 dB**

| **Modulation** | **Code rate** | ***C/N* (dB)** |
|---|---|---|
| **QPSK** | 1/2 | 11.5 |
| **QPSK** | 2/3 | 14.7 |
| **QPSK** | 3/4 | 16.7 |
| **16-QAM** | 1/2 | 17.2 |
| **16-QAM** | 2/3 | 20.9 |
| **16-QAM** | 3/4 | 23.1 |
| **64-QAM** | 1/2 | 22.1 |
| **64-QAM** | 2/3 | 25.3 |
| **64-QAM** | 3/4 | 27.5 |

# *C/N* for diversity reception in a static Rayleigh channel

## *Measurement method*

The measurement of the minimum *C/N* for good DVB-T diversity reception in a static Rayleigh channel was similar to the single-antenna measurement. The difference is that two SFQ signal generators were used to generate the DVB-T signal that was fed to the two inputs of the DiBcom diversity receiver.

One generator created the “master” DVB-T signal which was fed to the 12-path fading simulator. After mixing in a specific amount of thermal noise, the master signal was fed to antenna input 1 of the DVB-T receiver. The I and Q components of the DVB-T master signal were also routed to a “slave” signal generator, where they were fed to the slave’s IQ modulator and 12-path fading simulator. The slave generator output signal, mixed with thermal noise, was connected to antenna input 2 of the DVB-T receiver. Both generators had the same signal level, profile setting and the same thermal noise level, in order to set a specific *C/N* level at measurement time.

The receiver part of the measurement set-up was the same as for the single-antenna static measurements, except that both receiver inputs were used. Like in the single input case, the QEF criterion (BER = $2*10^{-4}$) was used to assess the reception quality.

The settings for the relative power, the delay, the phase and the profile for the 12 paths used were the same as in the single-antenna receiver case. A set of 50 measurements with different phase sets was made for every mode and code rate.

## Measurement results

The cumulative probability distributions of the measured *C/N* values for 16-QAM 2/3 using the diversity receiver, for the quality criteria QEF and $ESR_5$, are depicted in *Fig. 6*.

Comparing the two distributions in *Fig. 6*, we see that the minimum *C/N* value which satisfies the QEF quality criterion is 1.1 dB higher than the *C/N* value necessary to satisfy the $ESR_5$ criterion.

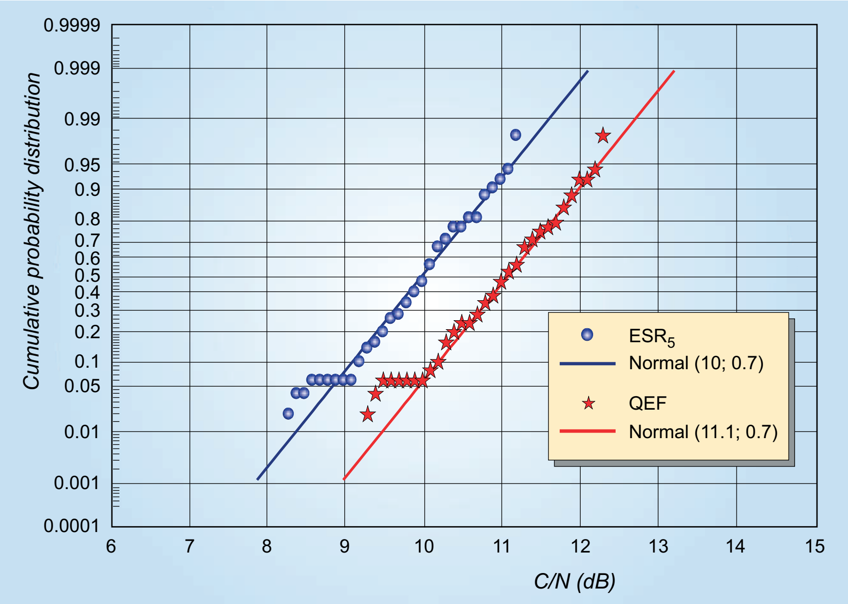


**Figure 6**
**Cumulative probability distribution of the *C/N* values in the static Rayleigh channel for 16-QAM 2/3 at 610 MHz with quality criteria QEF and $ESR_5$, using a diversity receiver.**

To show the advantage of diversity reception, the cumulative probability distributions for single and diversity reception are shown in *Fig 7*.

The diversity reception reduces the median *C/N* value by 4.3 dB, relative to the single-antenna case, when using 16-QAM 2/3. The reduction increases at higher time ratios, because the standard deviation of the *C/N* probability distribution for diversity reception is smaller than the one for single reception. At the 0.99 time ratio (good reception for 99% of the time) the *C/N* value reduction is higher by about 5 dB.

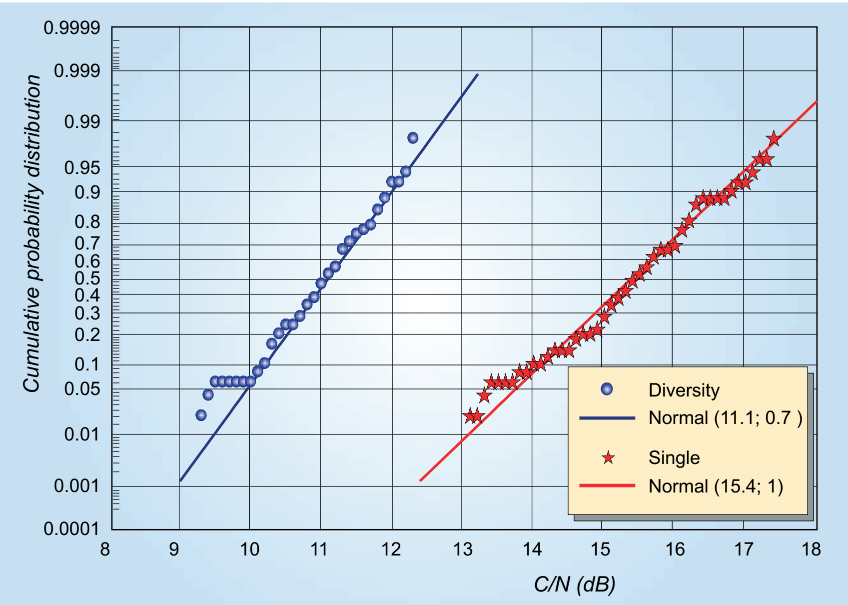


**Figure 7**
**Cumulative probability distribution of the *C/N* values in the static Rayleigh channel for 16-QAM 2/3 at 610 MHz with quality criterion QEF – comparison between single and diversity reception**

In *Fig. 8* the cumulative probability distributions for 16-QAM at

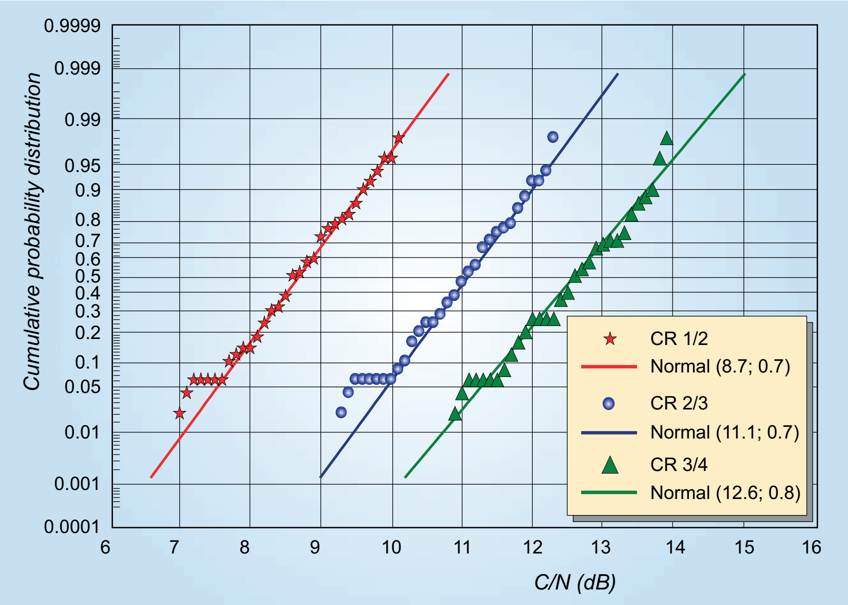


**Figure 8**
**Cumulative probability distribution of the C/N-values at 610 MHz, mode 16-QAM 1/2, 2/3 and 3/4 in the static Rayleigh channel, at diversity reception, with quality criteria QEF**

three code rates (1/2, 2/3 and 3/4) are shown.

The median *C/N* value decreases by 1.5 dB when the code rate is reduced from 3/4 to 2/3, and decreases a further 2.4 dB if the code rate is reduced to 1/2.

The cumulative distributions of the *C/N* values shown in *Fig. 6* and *Fig. 8* are normal distributions, defined by the median value and the standard deviation. The parameters of the measured *C/N* distributions shown in *Fig. 6* and *Fig. 8* and for the other modes we measured are given in *Table 12*.

To get receiver-independent values, the receiver implementation loss was subtracted. There are no simulation results giving *C/N* values for diversity reception, so implementation loss values in a diversity channel cannot be calculated. We assume that the implementation loss values for diversity reception are the same as the values for single-antenna reception given in *Table 5*. The receiver-independent parameters for the *C/N* probability distributions are given in *Table 13*.

For a standard receiver with an implementation loss of 3 dB and for a 99% probability of good reception in an elementary area, the minimum *C/N* has the values given in *Table 14*.

The *C/N* value of 15.3 dB for 16-QAM 2/3 in *Table 14* is 1.9 dB lower than the value of 17.2 dB given in the Chester agreement [2] for good DVB-T reception in a static Rayleigh channel (for a receiver with an implementation loss of 3 dB).

**Table 12**
**Parameters of the normal probability distribution of the *C/N* values measured with a DiBcom diversity receiver in a static Rayleigh channel at 610 MHz:**
**Quality criteria = QEF**

| | | *C/N* | |
|---|---|---|---|
| **Modulation** | **Code rate** | **Median value (dB)** | **Standard dev. (dB)** |
| **QPSK** | 1/2 | 3.5 | 0.7 |
| **QPSK** | 2/3 | 5.6 | 0.8 |
| **QPSK** | 3/4 | 6.8 | 0.7 |
| **16-QAM** | 1/2 | 8.7 | 0.7 |
| **16-QAM** | 2/3 | 11.1 | 0.7 |
| **16-QAM** | 3/4 | 12.6 | 0.8 |
| **64-QAM** | 1/2 | 13.2 | 0.7 |
| **64-QAM** | 2/3 | 16.5 | 0.8 |
| **64-QAM** | 3/4 | 18.5 | 0.8 |

**Table 13**
**Parameters of the receiver-independent *C/N* normal probability distributions in a static Rayleigh channel at 610 MHz, in the case of diversity reception**
**Quality criteria = QEF**

| Modulation | Code rate | *C/N* Median value (dB) | *C/N* Standard dev. (dB) |
|---|---|---|---|
| QPSK | 1/2 | 2.9 | 0.7 |
| QPSK | 2/3 | 5.0 | 0.8 |
| QPSK | 3/4 | 6.2 | 0.7 |
| 16-QAM | 1/2 | 8.4 | 0.7 |
| 16-QAM | 2/3 | 10.7 | 0.7 |
| 16-QAM | 3/4 | 12.3 | 0.8 |
| 64-QAM | 1/2 | 13.2 | 0.7 |
| 64-QAM | 2/3 | 15.8 | 0.8 |
| 64-QAM | 3/4 | 17.6 | 0.8 |

**Table 14**
***C/N* values required for good portable diversity reception in a static Rayleigh channel, over 99% of the area, for a receiver with an implementation loss of 3 dB**
**Quality criteria = QEF**

| Modulation | Code rate | *C/N* (dB) |
|---|---|---|
| QPSK | 1/2 | 7.5 |
| QPSK | 2/3 | 9.9 |
| QPSK | 3/4 | 10.8 |
| 16-QAM | 1/2 | 13.0 |
| 16-QAM | 2/3 | 15.3 |
| 16-QAM | 3/4 | 17.2 |
| 64-QAM | 1/2 | 17.8 |
| 64-QAM | 2/3 | 20.7 |
| 64-QAM | 3/4 | 22.5 |

## *C/N* for diversity reception in a portable Rayleigh channel

### *Measurement method*

The measurement set-up consisted of two DVB-T generators, a receiver and an MPEG-2 analyzer. It was similar to the set-up used for the static *C/N* measurements, with the addition of the MPEG-2 analyzer.

For the diversity measurements, as in the single-antenna measurements, the standard SFQ channel profile "TU 12 path" was used as a time-varying portable channel simulation, at a very low velocity of 0.4 km/hr. The fading simulators of both generators were set to the same profile, and the level and *C/N* setting for every measurement was the same for both generators.

The MPEG-2 transport stream errors (synchronization loss and transport stream error flag set) were used to assess the transmission errors according to the $ESR_5$ criterion. The internal thermal noise of both DVB-T generators was set in order to obtain a defined *C/N* value and the transport stream errors were recorded for one hour. The error record was analyzed in accordance with the $ESR_5$ criterion and the ratio < *intervals with good reception* / *all intervals* > within the measurement hour was calculated in the same way as for single-antenna reception.

The measurements were made for three to six *C/N* settings at each modulation and code rate, in order to get the points with the ratio in the range 0.01 to 0.99. The value pairs – *C/N* value and "the time ratio of good reception in conformity with the $ESR_5$ criterion" – were represented in a probability diagram.

### *Measurement results*

The measurement results for *C/N* are depicted in *Fig. 9* as blue points**.** The blue line through the points is the cumulative probability distribution of a normal distribution with 12.1 dB median value and a standard deviation of 0.7 dB. The minimum *C/N* values for good DVB-T reception in the simulated portable channel are normally distributed, because they are distributed close to the blue line.

The *C/N* distribution for diversity reception in a static channel from *Fig. 6* (quality criterion = QEF) is also shown (as red stars), to underline the difference relative to the time-varying case.

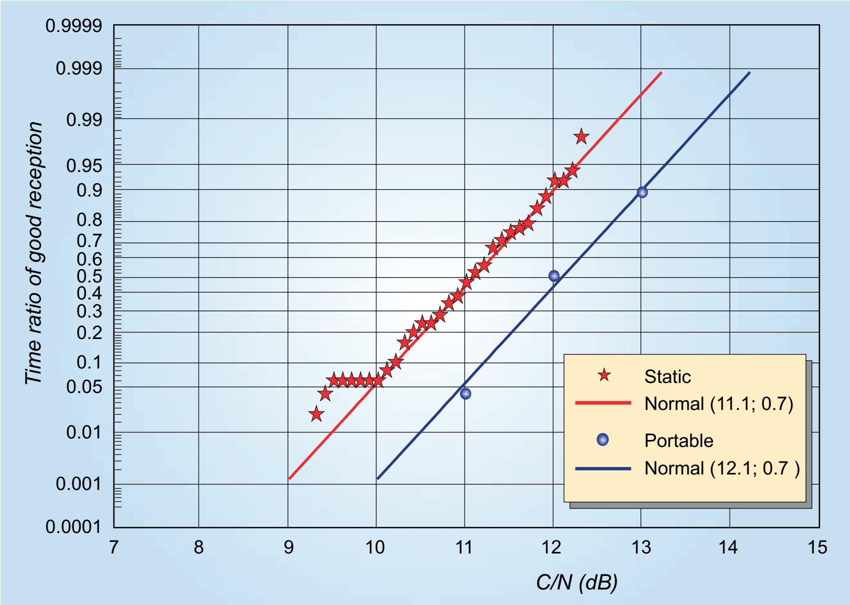


**Figure 9**
**Time ratio of good diversity reception versus *C/N* in a time-varying portable channel using quality criteriion $ESR_5$, and the cumulative probability distribution of the *C/N* values for diversity reception of 16-QAM 2/3 in a static Rayleigh channel, using quality criterion QEF**

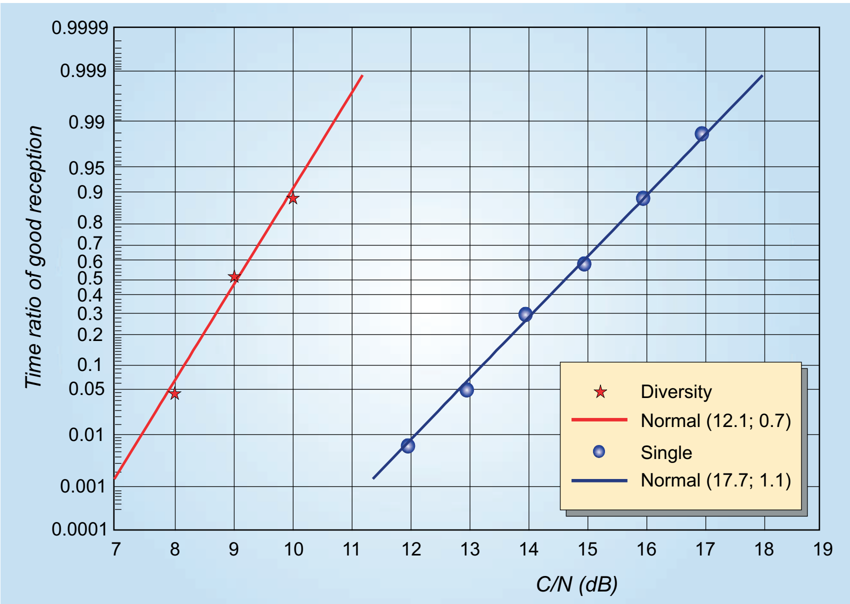


**Figure 10**
**Time ratio of good diversity reception versus *C/N* in a time-varying portable channel for 16-QAM 2/3 at 610 MHz, comparing single and diversity reception using quality criterion $ESR_5$**

The median *C/N* value for portable (time-varying) diversity reception, measured using the quality criterion $ESR_5$, is 1 dB higher than the corresponding value for the static Rayleigh channel, measured using the quality criterion QEF. The standard deviation of 0.7 dB is the same in the static and the time-varying portable channel, and is significantly lower than the 1 dB in the single-antenna reception case.

In *Fig. 10* the *C/N* values for portable (time-varying) reception, both single and diversity, are shown together in order to highlight the benefits of using diversity reception. It can be seen that diversity reception reduces the median *C/N* value relative to the single-antenna case by 5.6 dB and, for a time ratio of 0.99, by 6.5 dB!

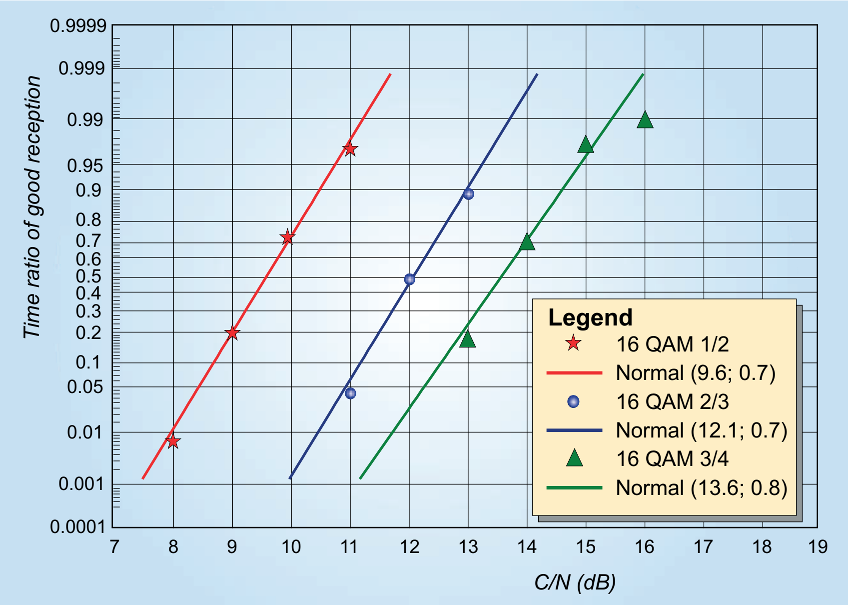


**Figure 11**
**Time ratio of good reception versus *C/N* at 610 MHz for 16-QAM 1/2, 2/3 and 3/4 in a time-varying portable channel, using diversity reception: Quality criteria = $ESR_5$**

In *Fig. 11* the time ratio of good reception versus *C/N* in the simulated time-varying portable channel is shown for diversity reception of 16-QAM at code rates of 1/2, 2/3 and 3/4. The standard deviations are almost the same for the three code rates considered, with a value around 0.7 dB.

Reducing the code rate from 3/4 to 2/3 allows a *C/N* or power reduction of 1.5 dB for the same transmission quality. Further reducing the code rate to 1/2 allows a supplementary *C/N* or power reduction of 2.5 dB.

The parameters of the portable *C/N* time probability distributions in *Fig. 11* for 16-QAM 1/2, 2/3 and 3/4, and for the other measured modes, are shown in *Table 15*.

The *C/N* values in *Table 15*, which are required for good reception in conformity with the $ESR_5$ criteria, are receiver-dependent. To get receiver-independent values, the receiver-dependent implementation loss should be subtracted. Implementation loss values in a portable diversity channel are not available. If we assume that the static values in *Table 5* are valid for the portable channel, we get the parameters of the *C/N* probability distributions shown in *Table 16*.

For good reception 99% of the time in conformity with the $ESR_5$ criteria, the *C/N* values should be the median values plus 2.33 times the standard deviation.

*Table 17* shows the minimum *C/N* values for a 99% probability of good diversity portable reception in conformity with the $ESR_5$ criteria, for a receiver with an implementation loss of 1 dB.

**Table 15**
**Parameters of the time probability distributions of the measured *C/N* values in a portable channel at 610 MHz, using diversity reception (DiBcom receiver): Quality criteria = $ESR_5$**

| | | *C/N* | |
|---|---|---|---|
| **Modulation** | **Code rate** | **Median value (dB)** | **Standard dev. (dB)** |
| QPSK | 1/2 | 4.7 | 0.8 |
| QPSK | 2/3 | 6.7 | 0.7 |
| QPSK | 3/4 | 7.7 | 0.8 |
| 16-QAM | 1/2 | 9.6 | 0.7 |
| 16-QAM | 2/3 | 12.1 | 0.7 |
| 16-QAM | 3/4 | 13.6 | 0.8 |
| 64-QAM | 1/2 | 14.0 | 0.7 |
| 64-QAM | 2/3 | 17.5 | 0.8 |
| 64-QAM | 3/4 | 19.2 | 0.7 |

**Table 16**
**Parameters of the receiver-independent *C/N* normal probability distrbutions in a portable Rayleigh channel at 610 MHz, using diversity reception:**
**Quality criteria = $ESR_5$**

| Modulation | Code rate | *C/N* Median value (dB) | *C/N* Standard dev. (dB) |
|---|---|---|---|
| QPSK | 1/2 | 4,1 | 0,8 |
| QPSK | 2/3 | 6,1 | 0,7 |
| QPSK | 3/4 | 7,1 | 0,8 |
| 16-QAM | 1/2 | 9,3 | 0,7 |
| 16-QAM | 2/3 | 11,7 | 0,7 |
| 16-QAM | 3/4 | 13,3 | 0,8 |
| 64-QAM | 1/2 | 14,0 | 0,7 |
| 64-QAM | 2/3 | 16,8 | 0,8 |
| 64-QAM | 3/4 | 18,3 | 0,7 |

**Table 17**
***C/N* values required for good portable diversity reception in conformity with the $ESR_5$ criterion for 99% of the time, for a receiver with an implementation loss of 1 dB**

| Modulation | Code rate | *C/N* (dB) |
|---|---|---|
| QPSK | 1/2 | 7.0 |
| QPSK | 2/3 | 8.7 |
| QPSK | 3/4 | 10.0 |
| 16-QAM | 1/2 | 11.9 |
| 16-QAM | 2/3 | 14.3 |
| 16-QAM | 3/4 | 16.2 |
| 64-QAM | 1/2 | 16.6 |
| 64-QAM | 2/3 | 19.7 |
| 64-QAM | 3/4 | 20.9 |

When calculating coverage areas for portable diversity DVB-T reception of 16-QAM 2/3, the decrease of 2.9 dB in the *C/N* value, from the 17.2 dB value given in the Chester agreement [2], to the 14.3 dB value shown in *Table 17*, can be taken into consideration. For the other modulation modes also, the values given in *Table 17* can be used instead of the values given in the ETSI Specification [1].

The *C/N* values given in *Table 17* are suitable for up-to-date diversity receivers with an implementation loss of no more than 1 dB.

## Conclusions

Field measurements have shown that the minimum *C/N* values given in the ETSI DVB-T Standard [1], for good-quality portable reception in a static Rayleigh channel, are too low – even when increased by 3 dB to account for the receiver implementation loss. They have also shown that the multipath field, the usual field encountered in portable reception, is almost never static but varying in time. The received signal power in such a field is fluctuating even if the antenna is fixed, because the field strength is changing continuously. A DVB-T receiver is less sensitive in a time-varying portable channel than in a static channel, and therefore the minimum *C/N* values in *realistic* portable channels are higher.

It has been shown that in a time-varying channel, the reception quality description has to include time information, such as the *C/N* value for good DVB-T portable reception for 99% of the time.

The *C/N* values given in [1] were found by transmission simulations in a static “frozen” Rayleigh channel. New minimum *C/N* values for good portable reception in urban areas were measured using a more realistic portable channel simulation. To take into account the time variation of the field strength, a mobile “typical urban” channel at very low velocity (0.4 km/h) was used to simulate the portable channel.

Up until now in network planning, the *C/N* values given in [1], increased by a receiver implementation loss of 3 dB, have been used. However, measurements made with new DVB-T receivers have shown the implementation loss to be around 1 dB only. New *C/N* planning values – that take channel time-variance into consideration – can therefore now include a receiver implementation loss of just 1 dB, as a result of receiver improvements.

**Raul Schramm** studied Electronic Engineering at the Polytechnic Institute of Bucharest. After completing his studies in 1971, he joined the Polytechnic Institute working as an assistant and later as assistant professor for microwave technology. In 1983 he joined the *Institut Für Rundfunktechnik* (IRT) in Munich, where he was involved in work concerning terrestrial radiowave propagation.

Since the transition to digital broadcasting, Mr Schramm has been involved in the development of test methods and test systems for digital broadcast systems, and in carrying out field measurements to find the terrestrial transmission-channel parameters for DAB and DVB-T.

The measurements have shown that, in a realistic time-varying portable channel, the minimum *C/N* for good reception 99% of the time is 20.9 dB, when using (8k) 16-QAM 2/3 and a receiver with an implementation loss of no more than 1 dB. This is an increase of 3.7 dB relative to the 17.2 dB value considered so far in a static Rayleigh channel (for a receiver with an implementation loss of 3 dB). For the other modes and code rates, the minimum *C/N* values for good reception 99% of the time are given in *Table 11*.

Diversity reception, using two separated receiving antennas, improves the receiver sensitivity by more than 6 dB. For a receiver with 1 dB implementation loss, the minimum *C/N* value is 14.3 dB for good diversity reception of 16-QAM 2/3, for 99% of the time. For the other modes and code rates, the minimum *C/N* values are given in *Table 17*.

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[2] CEPT: **The Chester 1997 Multilateral Coordination Agreement relating to Technical Criteria, Coordination Principles and Procedures for the Introduction of Terrestrial Digital Video Broadcasting (DVB-T)**
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