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DTT Comparison of 64QAM(2/3) with 16QAM(3/4): Co-channel Interference from PAL, Echoes and Impulsive Interference

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Abstract

This white paper collates results comparing the performance of the two DVB-T modes currently in use in the UK. Namely, 64 QAM rate 2/3 and 16 QAM rate 3/4, both using 2K carriers with a 7 μ s guard interval. Three different sources of impairment are measured: Co-channel interference from an analogue PAL signal, multipath propagation resulting in one echo inside or outside the guard interval and impulsive interference. Results are presented in a novel manner as 'noise bucket' plots. These plots are used to quantify the improvement in performance that can be achieved with 16 QAM rate 3/4 over 64 QAM rate 2/3.

Key words: DVB-T, multipath, noise bucket, END, OFDM

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1 Introduction

In June 2002 a series of field trials were carried out from the Crystal Palace transmitter in order to evaluate the relative merits of different DVB-T modes being considered for the re-launch of DTT in the UK. Two modes of particular interest were the mode used since start of service in November 1998 – 64 QAM, rate 2/3, and 16 QAM, rate 3/4 – which had been used for engineering trials in 1997 [1]. Both are 2K modes with guard interval duration of $7 \mu\text{s}$, which corresponds to 1/32 of the OFDM symbol duration. The Independent Television Commission (ITC) has now mandated these two modes for use in the UK. In the following, and for brevity, these modes will be referred to as 64Q and 16Q, respectively.

This white paper presents a performance comparison between these two modes in the presence of three different types of impairment:

- Co-channel interference (CCI) coming from an analogue PAL transmitter
- Multipath propagation resulting in one echo located inside or outside the guard interval (echoes delayed $3.5 \mu\text{s}$ and $14 \mu\text{s}$ respectively)
- Impulsive interference (II)

A number of DVB-T receivers were used for the CCI and multipath tests, whereas just one DVB-T receiver exhibiting a typical performance was used for the II tests. The results collected here quantify the improvement in performance that is achieved with the 16Q mode compared with the 64Q mode.

The final report issued by the Digital Television Group (DTG) [2] documenting the mode trials of June 2002 included several II performance comparisons between 64Q and 16Q as submitted by the different partners collaborating in those tests. In some instances however, results regarding II were difficult to compare and even to analyse. Besides, although in both the subjective and objective in-home measurements done by the BBC, an improvement in II performance was noticed when switching from 64Q to 16Q, this was not so clear-cut in results reported by other partners.

Two different types of impulsive noise scenarios are analysed in this document. First, some field measurements of real traffic II are presented. These measurements did not make it to the final report in [2] for lack of time to process them. Second, a compilation of different laboratory measurements is presented using both real captured II and some test waveforms which have been proposed within the DTG as a test suite for II¹.

¹It is important to stress that a standard DVB-T receiver was used throughout all tests with no counter-measures available to mitigate impulsive interference.

2 Measurement methodology

2.1 Co-channel PAL and multipath

Measurements were made on ten different DVB-T receivers, according to DTG measurement guidelines. When making measurements, the now favoured approach within the DTG is to measure the point of failure² rather than the reference BER³ condition. This is the case for all the measurements presented here. For an Additive White Gaussian Noise (AWGN) channel the difference between the degradation criterion for reference BER and failure is typically 1.3 dB. For CCI coming from a PAL transmission, the best estimate for this difference between criteria is 2 dB.

By making several Equivalent Noise Degradation (END) measurements it has been possible to present the results in a novel manner as ‘noise bucket’ plots. For the case of CCI arising from PAL this is a plot of C/N versus C/I. For multipath channels with one echo, C/I is replaced by the echo attenuation relative to the main signal path. The asymptotic values of such a plot are the familiar AWGN C/N performance (no added interference) and the infinite END protection ratio performance (no added noise). It should be noted that the values of C/N used here refer to carrier power C and AWGN N at the receiver input.

It is worth mentioning that the convention followed here to obtain the carrier power C when an echo is present is to include the echo power. This can be done by actually measuring the total channel power with a modern spectrum analyser. Alternatively, if the system is calibrated with no echoes (main path only) then the total channel power can be calculated by performing a vector sum.⁴

2.2 Impulsive interference

For the field measurements, a BBC survey vehicle equipped with a mast fitted with a log-periodic antenna was used in areas where traffic interference was abundant. For each location one or more antenna orientations were used to try and vary the amount of traffic interference getting into the receiver. The number of UnCorrectable Errors (UCE) on the MPEG-2 transport stream and the number of times the receiver’s Forward Error Correction (FEC) decoder lost sync were averaged over a 1 minute period.

An objective ranking system reminiscent of the subjective one used in [2] was established to quantify the results. Namely, for each receiving set-up the two modes 64Q and 16Q were ranked according to Table 1.

	Ranking
Less than 1 UCE/min	1
Between 1 and 100 UCE/min	2
Sync errors and between 0 and 30 UCE/min	3
Sync errors and more than 30 UCE/min	4

Table 1: Ranking system used to evaluate traffic II performance.

² Where ‘failure’ criterion used from here onwards means the onset of uncorrectable errors within the transport stream resulting in picture artefacts.

³ The reference BER (BERref) adopted for DVB-T is 2×10^{-4} after the inner (Viterbi) decoding, which corresponds to Quasi-Error-Free (QEF) operation after the outer Reed-Solomon decoding. QEF is defined as a transport stream BER of less than 10^{-11} – equivalent to about one error per hour.

⁴ A useful trick here for a single echo is to set the centre carrier relative phase to 90° . This avoids ‘flat’ fade or variation due to a non-integer number of cycles in the channel frequency response. Thus a 0 dB echo will always increase the carrier power by 3 dB regardless of delay.

Two types of laboratory measurements were done. For the first one, we used real II waveforms captured at baseband (centred around 4.57 MHz and with a 7.61 MHz bandwidth) as part of a rather large II measurement campaign. For the second one, we employed an II test suite proposed within the DTG. Two different ways of presenting the results are used. In both the wanted signal level C remains fixed. When using captured II data, a plot of C/N versus C/I corresponding to the visual onset of UCE is used. Thus for each level of II there is a certain amount of Gaussian noise N we have to add in order to bring the DVB-T receiver close to its failure point. Note that when no II interference is added we are effectively measuring the AWGN C/N performance of the receiver.

The methodology followed with the DTG II test suite was different. No additional Gaussian noise was added and the C/I corresponding to 1 UCE per minute was recorded. The test suite comprises a set of seven trains of pulses, which differ in the number of pulses and the statistical distribution of the spacing between pulses. All pulses have the same amplitude and duration (250 ns). These waveforms are used to gate a source of wideband white Gaussian noise and the resulting signal is combined with the wanted signal. Regarding the computation of the interfering power, first the average power of the ungated noise source measured over the DVB-T bandwidth of 7.61 MHz is noted. This value is then divided by $224/\tau$ to obtain the gated noise power I, with 224 μ s being the useful OFDM symbol period and τ the ‘effective’ burst duration given by the number of pulses times the pulse duration. More details can be found in Section 3.3.3.

3 Results

3.1 Co-channel interference from PAL

Figure 1 shows C/N versus C/I plots for a PAL co-channel interferer for the two modes under consideration. A comparison of the average curves can be seen in Figure 2.

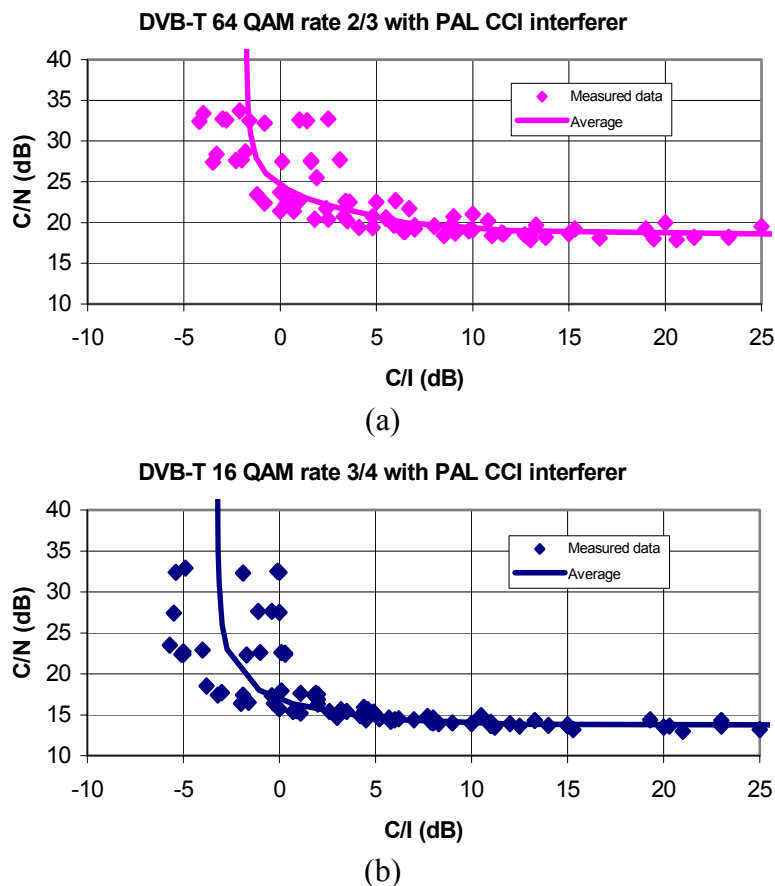


Figure 1: All measured PAL CCI data for modes 64Q (a) and 16Q (b).

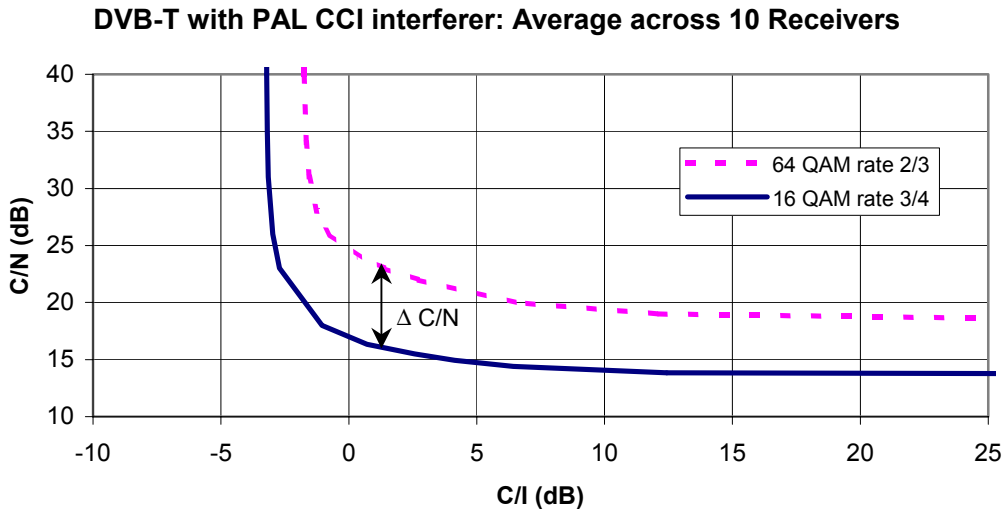


Figure 2: Average PAL CCI results for modes 16Q and 64Q.

With very low levels of interference, the performance is asymptotic to that of an AWGN channel. Here the C/N values are about 18 and 13.5 dB for 64Q and 16Q, respectively. The difference $\Delta C/N$ at the limit is 4.5 dB. For extreme levels of interference, 16Q shows about a 1.5 dB improvement over 64Q at the limit. However, it is far more informative to see how $\Delta C/N$ varies as a function of impairment level. In Figure 2 above, $\Delta C/N$ is marked for a C/I value of 1 dB. Here, $\Delta C/N$ is about 7 dB – considerably more than the AWGN channel value of 4.5 dB. The variation of $\Delta C/N$ as a function of impairment level is shown in Figure 3.

By presenting the results as shown in Figure 3 it can be seen that for severe to moderate PAL CCI (2 to 7 dB C/I say), 64Q requires 7 to 5.5 dB greater C/N than 16Q.

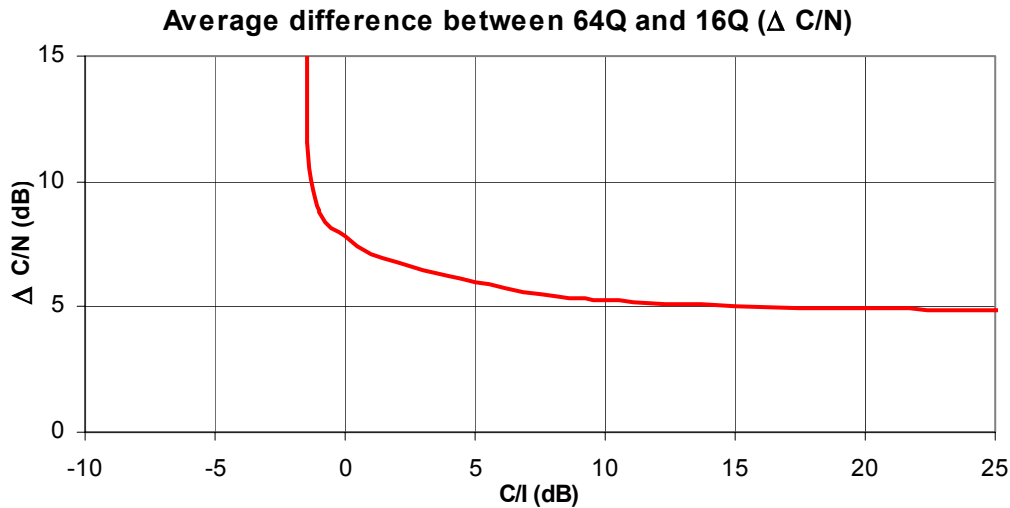


Figure 3: Additional C/N required for 64Q compared with 16Q.

3.2 Multipath channels with just one echo

Plots of C/N versus relative attenuation of a $3.5 \mu\text{s}$ echo within the guard interval for modes 64Q and 16Q are shown in Figures 4a and 4b respectively. Figure 4c shows a comparison of the averaged results. Analogous plots are those in Figure 5 for a $14 \mu\text{s}$ echo outside the guard interval.

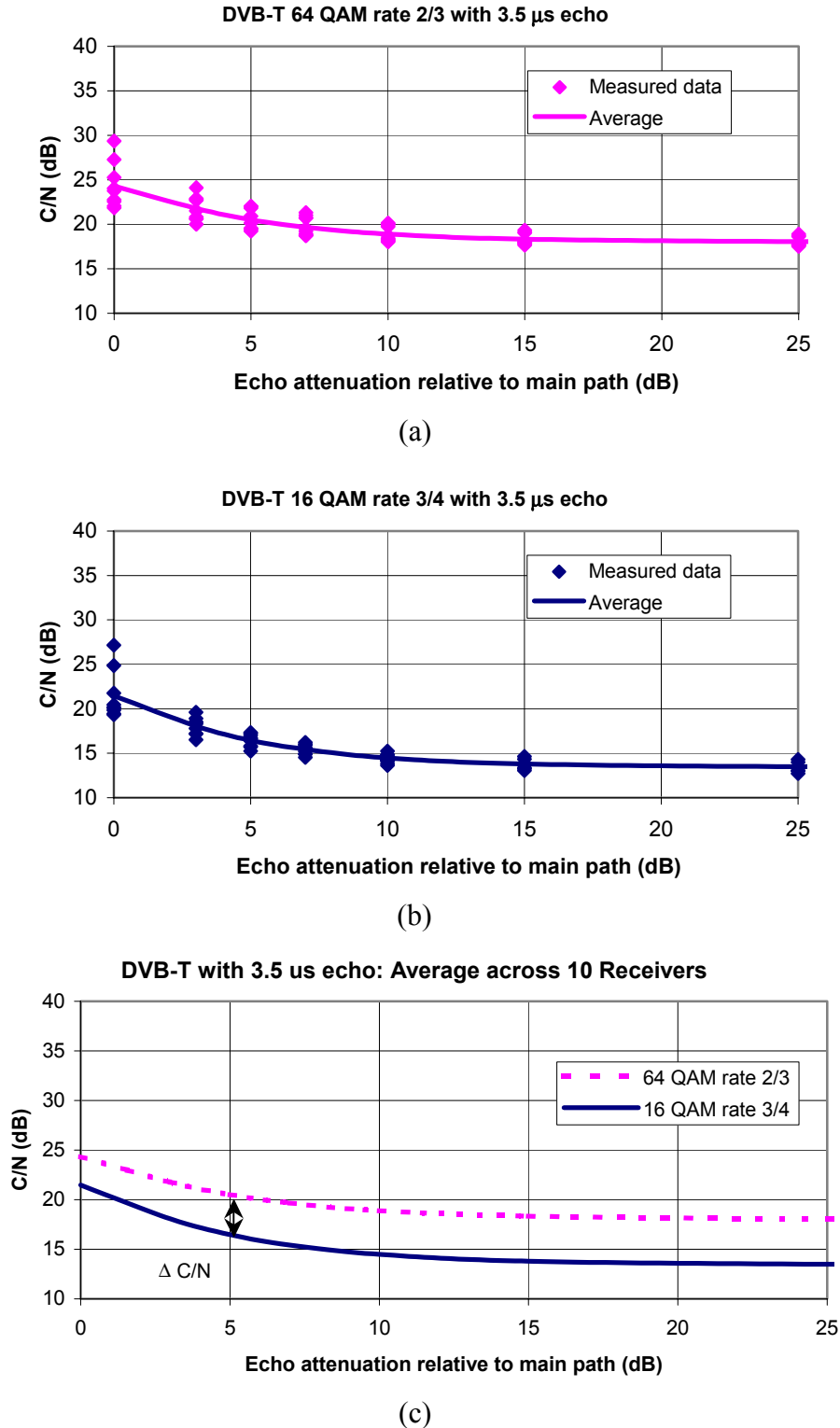
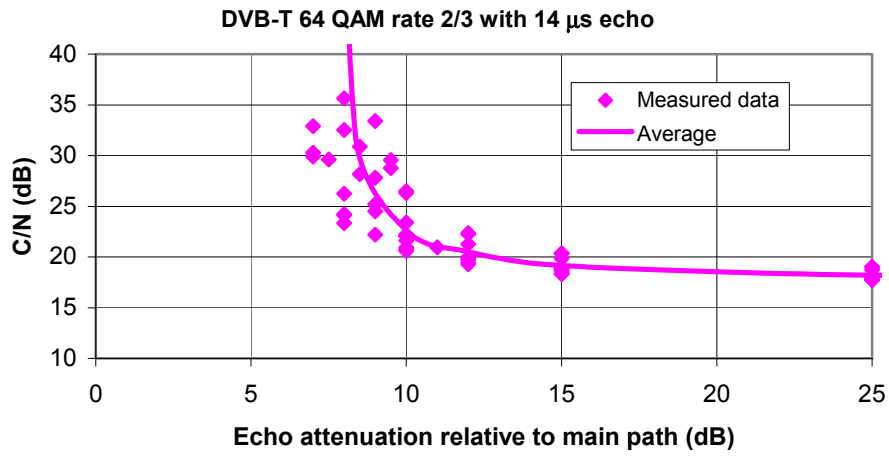
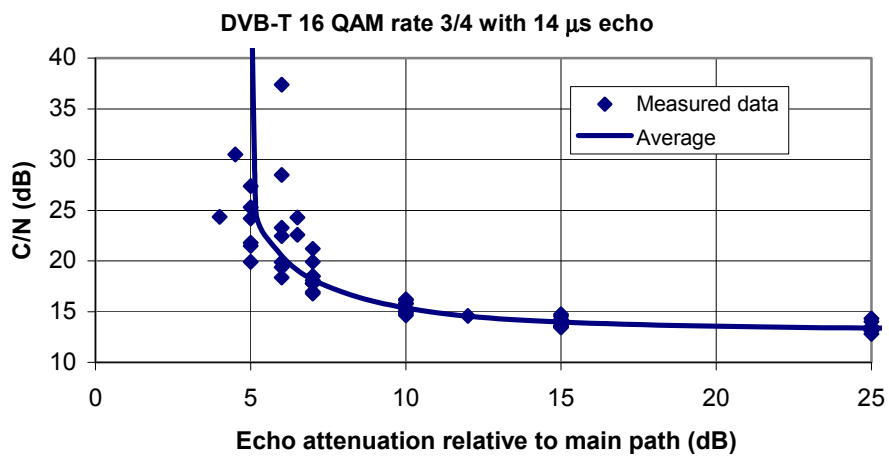


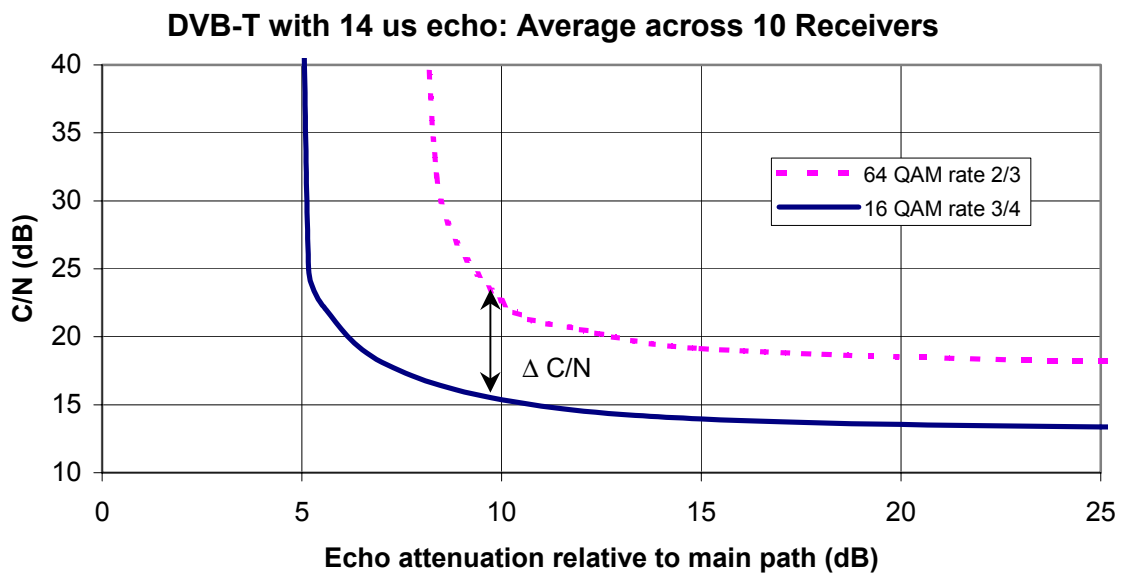
Figure 4: All measured data for a $3.5 \mu\text{s}$ echo for modes 64Q (a) and 16Q (b). A comparison of average results is shown in (c).



(a)



(b)



(c)

Figure 5: All measured data for a 14 μ s echo for modes 64Q (a) and 16Q (b). A comparison of average results is shown in (c).

For very low echo levels, the performance of the DVB-T system is asymptotic to that of an AWGN channel. C/N values in this region are about 18 dB for 64Q and 13.5 dB for 16Q.

For extreme 3.5 μ s echo levels (5 to 0 dB relative attenuation, see Figures 4a and 4b), 16Q degrades at a slightly greater rate than 64Q because of the weaker code rate, although at the 0 dB limit 64Q still requires 3 dB greater C/N than 16Q. For the 14 μ s echo, the maximum relative attenuation is less than 0 dB because this is outside the guard interval. At the limit, 16Q shows about 3 dB improvement over 64Q.

It is very informative to see how Δ C/N varies as a function of echo level. In figure 4c above, Δ C/N is marked for a 3.5 μ s echo attenuation value of about 5 dB. In this case, Δ C/N is about 4 dB – slightly less than the AWGN channel value of 4.5 dB. Analogously, we measure a Δ C/N of about 7.5 dB for a 14 μ s echo attenuation of 9.5 dB (see Figure 5c). This difference is considerably greater than the Gaussian value of 4.5 dB.

The variation of Δ C/N as a function of echo level, for both modes are shown in Figures 6a and 6b. Presenting the results in this fashion allows us to easily see the additional C/N requirements for 64Q compared to 16Q for all values of echo attenuation.

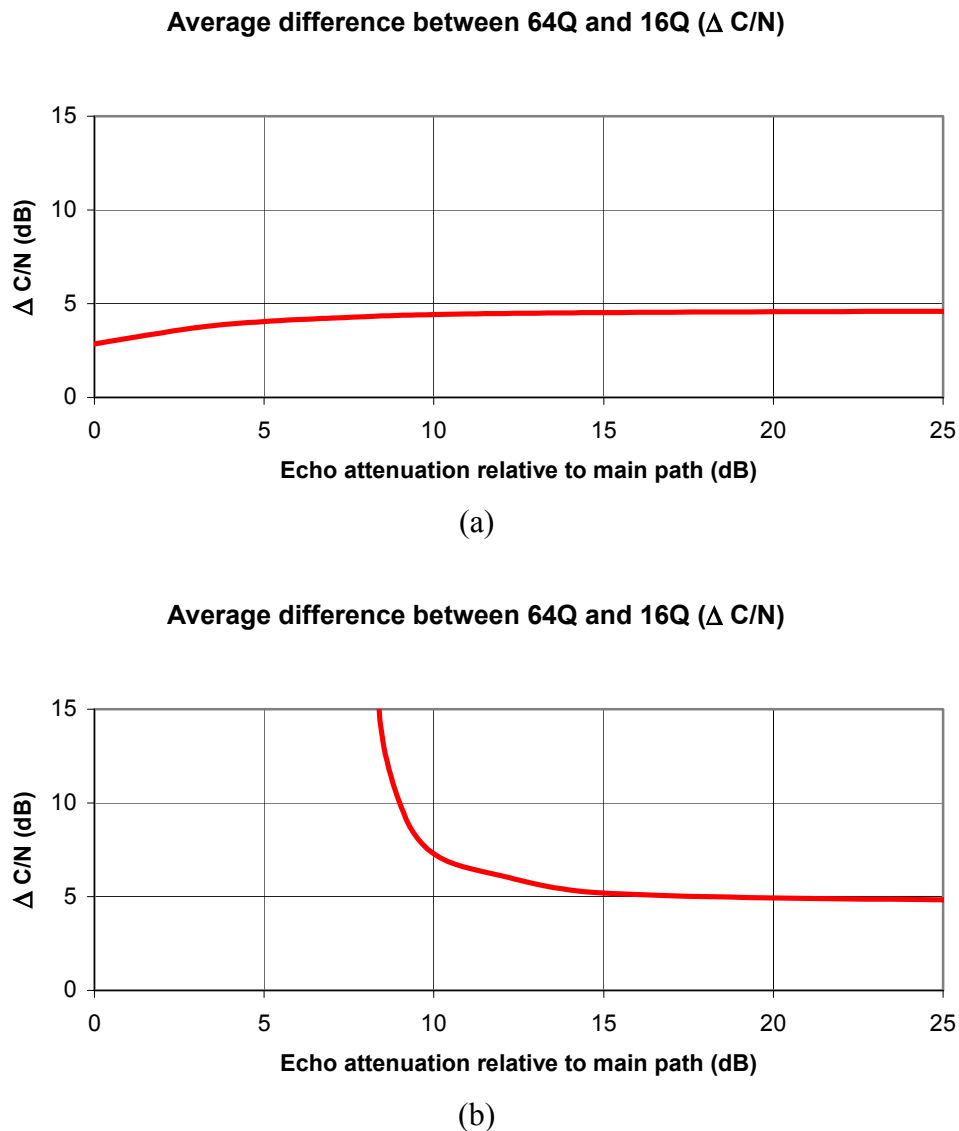


Figure 6: Additional C/N required for 64Q compared with 16Q as a function of the relative echo attenuation for a 3.5 μ s echo (a) and a 14 μ s echo (b).

3.3 Impulsive interference

3.3.1 Traffic impulsive interference

Table 2 shows for each location and measuring configuration the objective rankings (see Table 1) obtained for DVB-T transmission modes 64Q and 16Q.

LOCATION	RANKING	
	64Q	16Q
1, meas. 1	4	3
1, meas. 2	3	2
1, meas. 3	3	2
1, meas. 4	1	1
1, meas. 5	3	3
2, meas. 1	4	1
2, meas. 2	4	3
2, meas. 3	3	3
2, meas. 4	4	1
2, meas. 5	4	3
2, meas. 6	4	3
2, meas. 7	2	1
2, meas. 8	4	2
2, meas. 9	4	4
3, meas. 1	4	4
3, meas. 2	4	3
3, meas. 3	4	1
3, meas. 4	2	1
3, meas. 5	3	1
3, meas. 6	4	3
3, meas. 7	3	1
3, meas. 8	1	1
3, meas. 9	3	1
3, meas. 10	4	4
4, meas. 1	4	3
4, meas. 2	4	4
5, meas. 1	3	1
MEAN	3.3	2.2

Table 2: Objective rankings for traffic II and modes 64Q and 16Q.

In the bottom row, an average of all 27 measurements for each mode is shown. The improvement in performance achieved with 16Q is apparent. The receiver operating in 64Q lost sync at least once in 23 locations, whilst in comparison the receiver tuned to the 16Q channel lost sync only in 13 locations. In practice sync losses are much more disruptive to the viewer than picture and audio artefacts caused by UCEs. Note also that for every single measurement, mode 16Q usually outperforms mode 64Q.

3.3.2 Captured impulsive interference

Figures 7 to 10 show C/N versus C/I plots for four typical impulsive interference sources found in the real world. When no II is present in the system the C/N asymptotically approaches the value associated to the AWGN failure point which, for the receiver used in these tests, is 17.7 dB and 13.6 dB for 64Q and 16Q, respectively. Thus, the improvement of 16Q over 64Q for an AWGN channel is approximately 4 dB, much as expected.

As II is introduced in the system, the gap between the two curves remains roughly constant until the system performance starts to be determined by the impulsive noise instead of the Gaussian noise. This area corresponds to the bend in the blue curves associated to 64Q. When for this mode we have that most of the noise bucket is filled with II (vertical asymptote), 16Q still allows for more than a 10 dB increase in noise power before the receiver falls over. When II is the only source of impairment (C/N tends to infinity), we can measure the raw improvement in C/I obtained with a change to 16Q corresponding to the difference between the vertical asymptotes. This is shown in Table 3.

Captured II source	$\Delta C/I$ (dB)
Central heating	4
Traffic	7.5
Switching relay	4.4
Light switch	4

Table 3: C/I improvement for 16Q measured using captured II data.

Obviously, this improvement is lower bounded by the 4 dB measured for an AWGN channel. As the peak power to mean power ratio of the II is increased (e.g. traffic interference), clipping effects start to take place in the receiver and a greater advantage of up to 8 dB in interference power can be obtained from a change to 16Q.

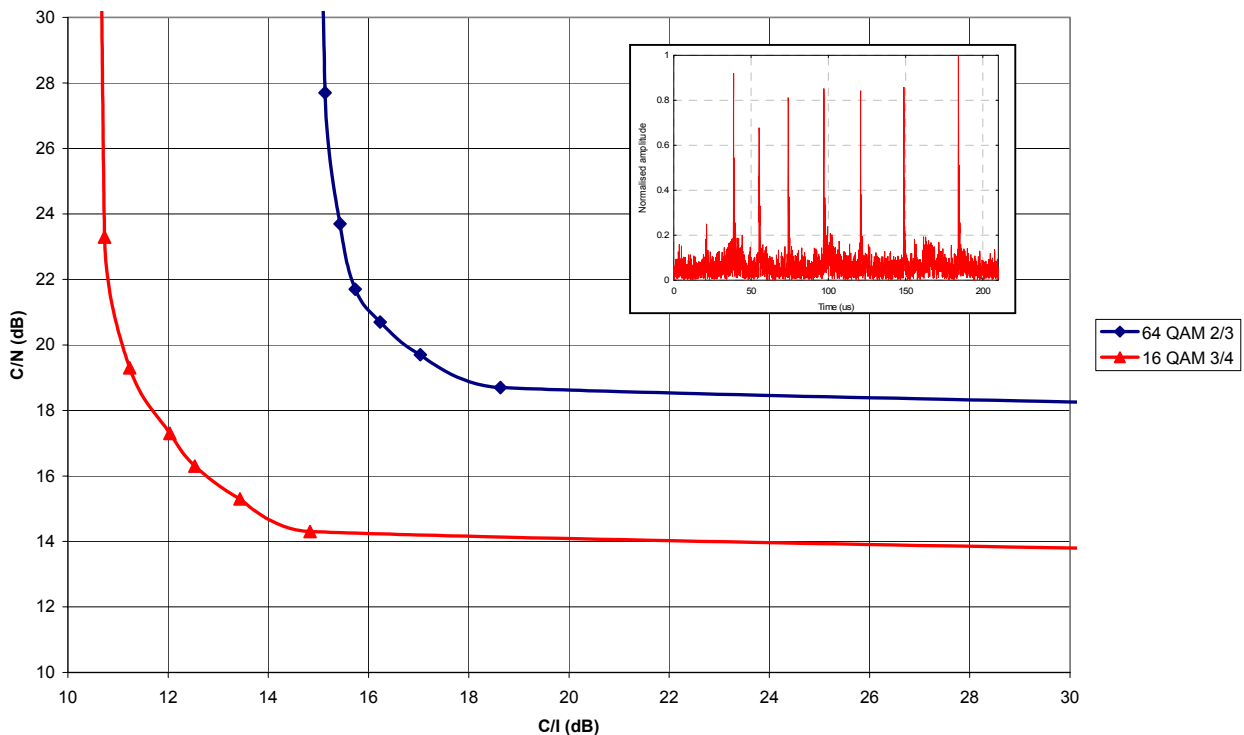


Figure 7: C/N v. C/I for the II shown in the inset plot captured from a central heating boiler.

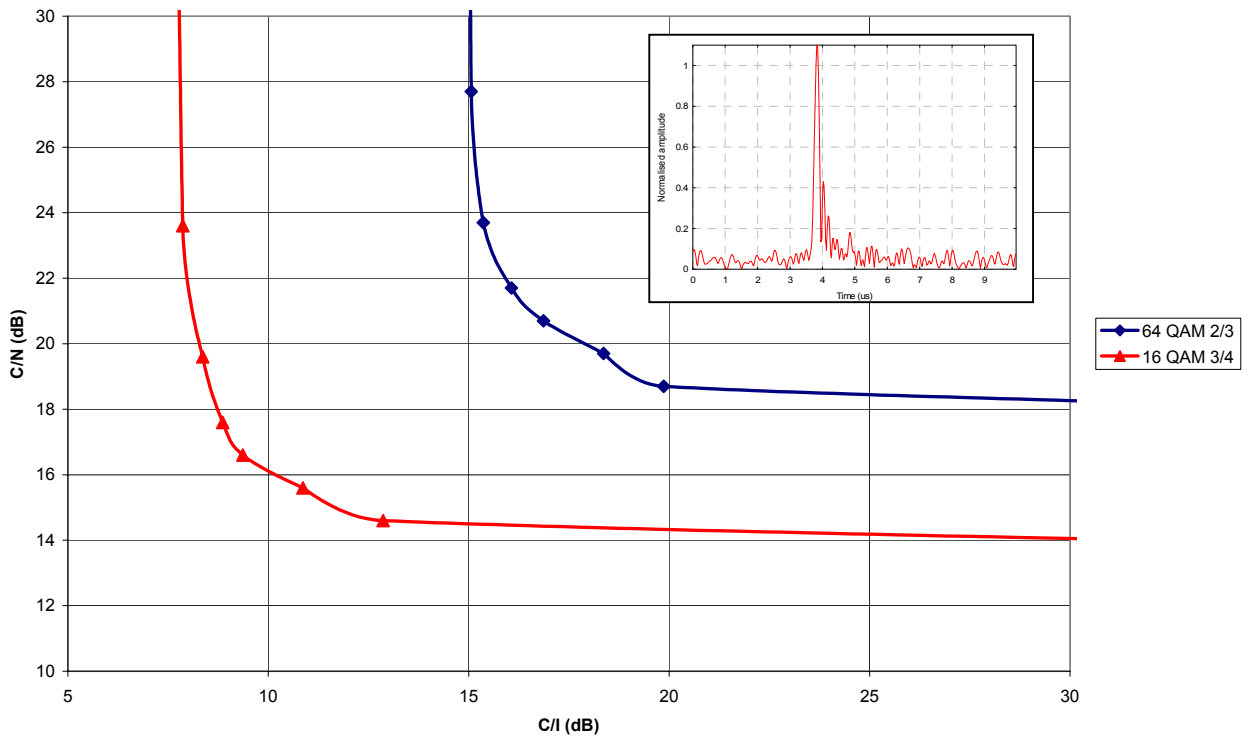


Figure 8: C/N v. C/I for the traffic II shown in the inset plot.

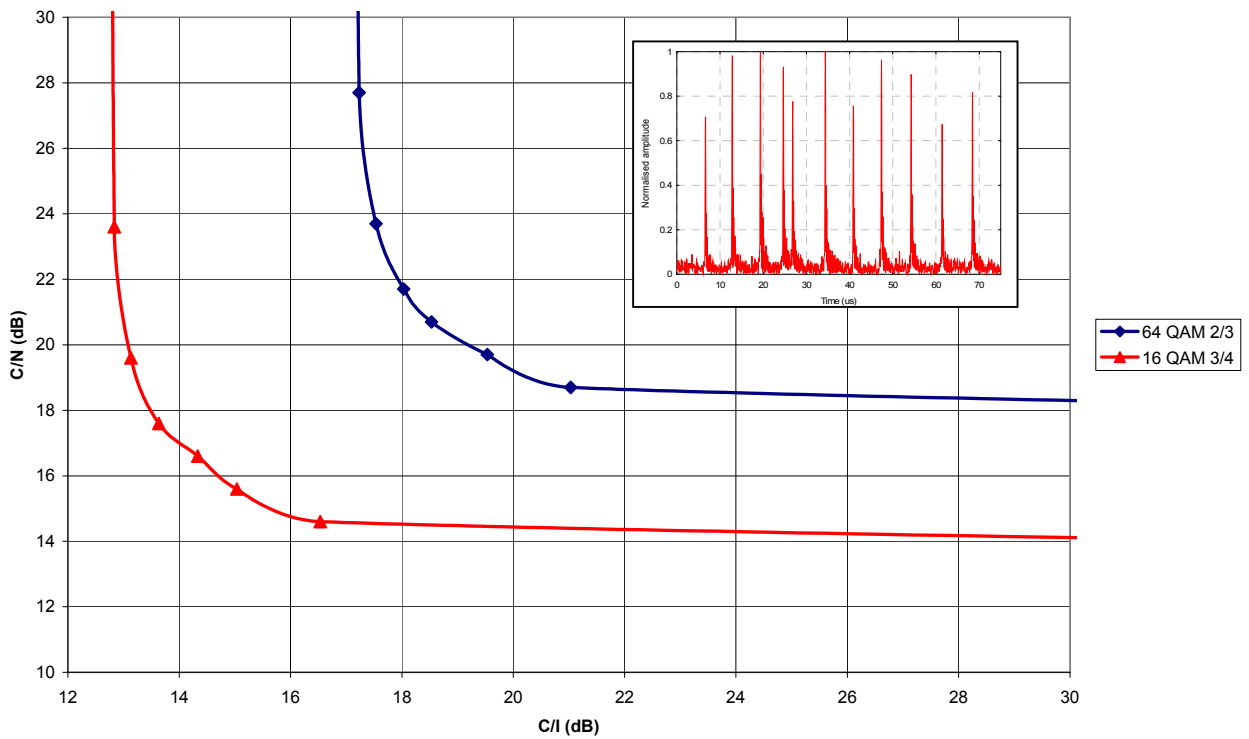


Figure 9: C/N v. C/I for the II shown in the inset plot. This was captured from a contrivance used to generate II by continually switching a relay.

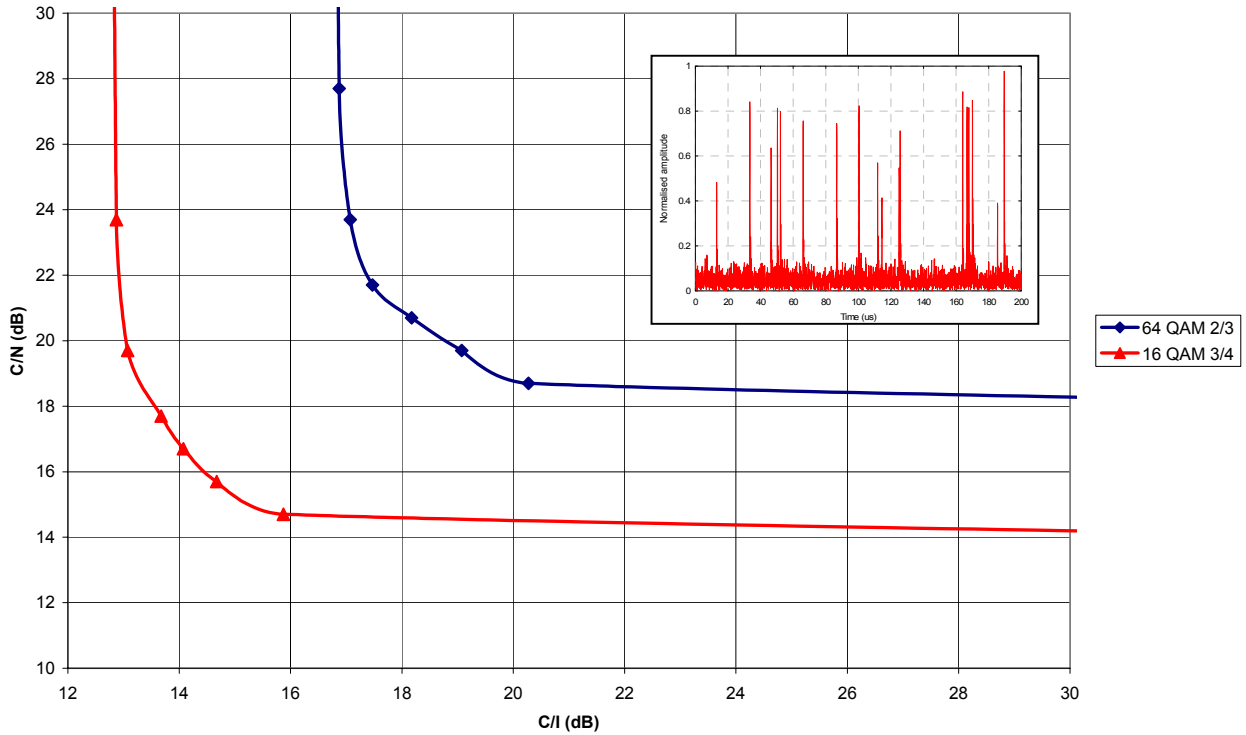


Figure 10: C/N v. C/I for the II shown in the inset plot as generated by a light switch.

3.3.3 Test waveforms proposed within the DTG

The test suite is formed by seven trains of pulses with 1, 2, 6, 10 or 20 pulses per burst. These bursts of pulses are repeated every 10 ms. The spacing between pulses depends on the actual source of interference the train of pulses is mimicking, and is given by a nominal value plus some uniformly distributed dithering. These parameters were obtained as a result of a thorough statistical analysis performed on more than 200 captures taken from an assorted set of II sources (such as light switches, boilers, domestic appliances and traffic). As mentioned before, II is simulated by switching an AWGN source with these trains of pulses. The following table gives a brief description of each test profile.

Number of pulses per burst	Pulse spacing (μs)
1	—
2	2 ± 0.5
	7.5 ± 2.5
	25 ± 20
6	25 ± 10
10	12.5 ± 2.5
20	1.5 ± 0.5

Table 4: II profiles used in the DTG working test suite.

For the sake of completeness and to account for other sources of II which do not easily fall into the train of pulses model, the test suite also includes two gated AWGN profiles. One uses a 100 μs pulse to gate the AWGN once every millisecond, whereas the other one gates the noise once every 10 ms using a 750 ns pulse.

A summary of the results obtained using the DTG test suite is shown in Table 5. On the first column, the effective useful duration of the II waveforms is shown. As the right-most column shows, the performance of a standard DVB-T receiver in the presence of II can be described using this single parameter.

The second column briefly describes the type of waveform (whether the gating signal is a train of pulses or just one pulse and, just in the first case, the pulse spacing PS). On the third column, the advantage of 16Q over 64Q is expressed as the difference in C/I values corresponding to 1 UCE per minute. Finally, the last column shows the improvement averaged over all waveforms having the same effective duration τ .

Effective duration τ (μs)	Gating signal description	$\Delta\text{C/I}$ (dB)	$\overline{\Delta\text{C/I}}$ (dB)
0.25	1 pulse	8.9	8.9
0.5	1 pulse	7.0	7.0
0.5	2 pulses PS = 2 ± 0.5	6.9	
0.5	2 pulses PS = 25 ± 20	7.1	
0.5	2 pulses PS = 7.5 ± 2.5	7.1	
0.75	1 pulse	7.0	
1.5	1 pulse	6.5	6.3
1.5	6 pulses	6.1	5.3
2.5	1 pulse	5.2	
2.5	10 pulses	5.4	
5	1 pulse	4.1	4.2
5	20 pulses	4.4	
14 to 18	100 μs pulsated PS = 1.5 ± 0.3	4.2	4.2
100	1 pulse	4.1	4.1

Table 5: C/I improvement for 16Q using the DTG test suite.

The performance of the DVB-T receiver for both 64Q and 16Q depends on the effective duration of the II, regardless of the number of gating pulses we use to synthesise it. For small τ , the improvement for the 16Q mode is rather substantial (between 7 and 9 dB when less than 0.5% of the useful OFDM symbol is corrupted). As τ increases, the mode change from 64Q to 16Q results in a smaller improvement, until the AWGN lower bound is reached.

4 Conclusions

In this paper a collection of performance measurements has been presented for the two DVB-T modes currently in use in the UK: 64Q (64 QAM, rate 2/3, 2K and 1/32 guard interval) and 16Q (16 QAM, rate 3/4, 2K and 1/32 guard interval). Only three types of impairment have been considered – co-channel PAL interference, multipath channels with a single echo (inside or outside the guard interval) and impulsive interference.

Results have been presented in a novel manner as ‘noise bucket’ plots, that is, a plot of C/N versus C/I for CCI from a PAL transmitter and impulsive interference, and C/N versus relative echo attenuation for multipath channels.

For all levels of PAL co-channel interference and 3.5 μs and 14 μs echo attenuation, the 64Q mode clearly requires a greater C/N than the 16Q mode.

A few values are extracted from Figures 3, 6a and 6b and tabulated right below. These three tables illustrate how much more C/N is required for 64Q compared to 16Q for each different sort of impairment.

C/I (dB)	Δ C/N (dB)
∞ (AWGN channel)	4.5
20	5.0
7	5.5
2	7
-2	∞ (64Q failed, 16Q OK)

(a)

Echo relative attenuation (dB)	Δ C/N (dB)
∞ (AWGN channel)	4.5
5	4.0
0	3.0

(b)

Echo relative attenuation (dB)	Δ C/N (dB)
∞ (AWGN channel)	4.5
20	5.0
10	7.5
8	∞ (64Q failed, 16Q OK)
5	N/A (16Q failed)

(c)

Table 6: Additional C/N required for 64Q compared with 16Q for (a) a co-channel analogue PAL interferer, (b) a 3.5 μ s echo and (c) a 14 μ s echo.

Regarding impulsive interference, a transmission mode change from 64 QAM rate 2/3 to 16 QAM rate 3/4 would bring the much desired benefit of having a more robust system against II. This has been verified with field measurements of traffic interference and lab measurements using both real captured II data and a suite of test waveforms proposed within the DTG:

- *Field measurements* show that, for a given receiving location, 16 QAM 3/4 is less prone to suffer from traffic II than 64 QAM 3/4. Given the nature of the experiment, it is difficult to extract a figure in dB but it is certain that the amount of disruptions per minute is smaller for the more rugged DVB-T mode.
- *Lab measurements* using the onset of UCE or one UCE per minute as failure criteria, confirmed that 16 QAM 3/4 is able to withstand between 4 and 9 dB more II than 64 QAM 3/4. The exact figure depends on the effective duration of the interference relative to the useful OFDM symbol period.

5 References

1. Nokes, C R, Pullen, I R, Salter, J E, "Evaluation of a DVB-T Compliant Digital Television System." IBC Conference Publication, 1997.
2. Digital Television Group (DTG), "Report of DTT (DVB-T) transmission mode trials carried out from the Crystal Palace transmitter", June 2002.

