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Digital TV Switchover:

An aerial test that uses a teletext test page

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Abstract

This white paper gives some of the technical background and detail of the work that we have been doing developing an on-screen indicator to assist digital switchover (DSO). We want to help viewers decide whether they need to improve their aerial installation to be reasonably certain of reliably receiving digital terrestrial transmissions (DTT) after DSO. Our work in this area forms a part of the overall work being conducted within the Digital Reception Prediction Group run by DigitalUK, the non-profit organisation leading the process of DSO in the UK.

The basic idea is very simple. Could the quality of existing analogue reception be used as a guide to the quality of future digital reception? A weak aerial signal results in snowy analogue pictures which may mean unreliable future digital reception. An assessment can be made of how snowy analogue pictures are in order to judge whether the aerial signal is too weak. However, viewers are not very comfortable making subjective assessments, so an indication using teletext as a test signal has now been developed. Less judgement is required for this test as this involves checking for missing blocks in a regular pattern. This so called 'aerial test' is currently being transmitted in teletext on page 284 on the four main analogue TV services in the UK.

A number of relevant relationships are considered in detail:

- Video signal-to-noise ratio versus RF vision carrier-to-noise ratio.
- Subjective analogue picture quality versus video signal-to-noise ratio.
- Video signal-to-noise ratio versus probability of error for teletext reception.
- RF vision carrier-to-noise ratio versus digital RF carrier-to-noise ratio.
- RF digital carrier-to-noise ratio versus error rate.
- Digital error rate versus subjective failure point.

There are some caveats that mean this test is not suitable for some switchover scenarios (the postcode database should be checked) and accuracy may be affected under certain conditions. Nevertheless, initial trials indicate that this 'aerial test' will be both a useful and simple test that will benefit the majority of viewers during DSO.

Additional key words: reception, antenna, digital margin

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Digital TV Switchover:

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1 Introduction

This white paper gives some of the technical background and detail of the work that we have been doing developing an on-screen indicator to assist digital switchover (DSO). We want to help viewers decide whether they need to improve their aerial installation to be reasonably certain of reliably receiving digital terrestrial transmissions (DTT) after DSO. Our work in this area forms a part of the overall work being conducted within the Digital Reception Prediction Group run by DigitalUK, the non-profit organisation leading the process of DSO in the UK.

The basic idea is very simple. Could the quality of existing analogue reception be used as a guide to the quality of future digital reception? Or, put another way; is my aerial system good enough for digital?

It is almost impossible to answer the second question accurately without an engineer's house call to assess aerial system components and signal levels. However, the idea of using the quality of existing analogue reception as a guide seems reasonably sound. To a first-order, signal quality for both analogue and digital signals is dependent upon the signal level arriving at the receiver input. With analogue television, the quality of the displayed picture can be used a guide to the quality of the received signal. However, this requires viewers to make a judgement. An experimental test logo was developed in order to help viewers make this judgement, but this still required the viewer to assess the visibility of a logo. Viewers are far more comfortable with objective 'go/no-go' decisions and so an indication using teletext[1] as a test signal has now been developed. Less judgement is required for this test as this involves checking for missing blocks in a regular pattern.

This so called 'aerial test' is currently being transmitted in teletext on page 284. The four main analogue TV services in the UK are transmitting this teletext test page.

2 Overview

There are a number of relationships which are relevant and are listed below These are discussed and additional detail is given in appendices.

- Video signal-to-noise ratio versus RF vision carrier-to-noise ratio.
- Subjective analogue picture quality versus video signal-to-noise ratio.
- Video signal-to-noise ratio versus probability of error for teletext reception.
- RF vision carrier-to-noise ratio versus digital RF carrier-to-noise ratio.
- RF digital carrier-to-noise ratio versus error rate.
- Digital error rate versus subjective failure point.

[1] The system used to transmit additional information within an analogue TV signal. Commercial channels originally called their teletext service Oracle. The BBC calls their teletext service Ceefax. Commercial channels now however, call their teletext service Teletext. All services are technically identical and will be discussed in detail later.

From these relationships it is possible to derive a relationship between existing analogue picture quality (including teletext) and *future* digital reception quality. During the Switchover process changes will include new digital transmissions on new channel allocations and an increase of transmitter power. “Future” in this context means the situation post DSO.

Analogue picture quality is quantified in terms of picture grade or scale, where “5” is the best and “1” is the very worst. In ‘technical speak’ the relevant parameter is video signal-to-noise ratio. One way of quantifying digital reception quality is RF digital margin, where 0 dB represents the minimum level where digital reception is possible.

As an aside, it is worth bearing in mind the overall aims of broadcasters concerning coverage, signal quality and DSO. Currently the four main analogue (PAL) TV services are transmitted such that 98.5% of households can achieve a minimum acceptable level of picture quality (grade 3) for 95% of the time. Post DSO, the aim is that 98.5% of households[2] will be able to receive digital services for 99% of the time. The time factor comes in because of distant interference issues which are weather related. Greater protection is sought for digital services because severe interference may cause service outage.

It is best to show some of these relationships (which we will detail later) as charts. The following chart gives an overall view of the relationship between existing analogue picture quality and future digital reception quality.

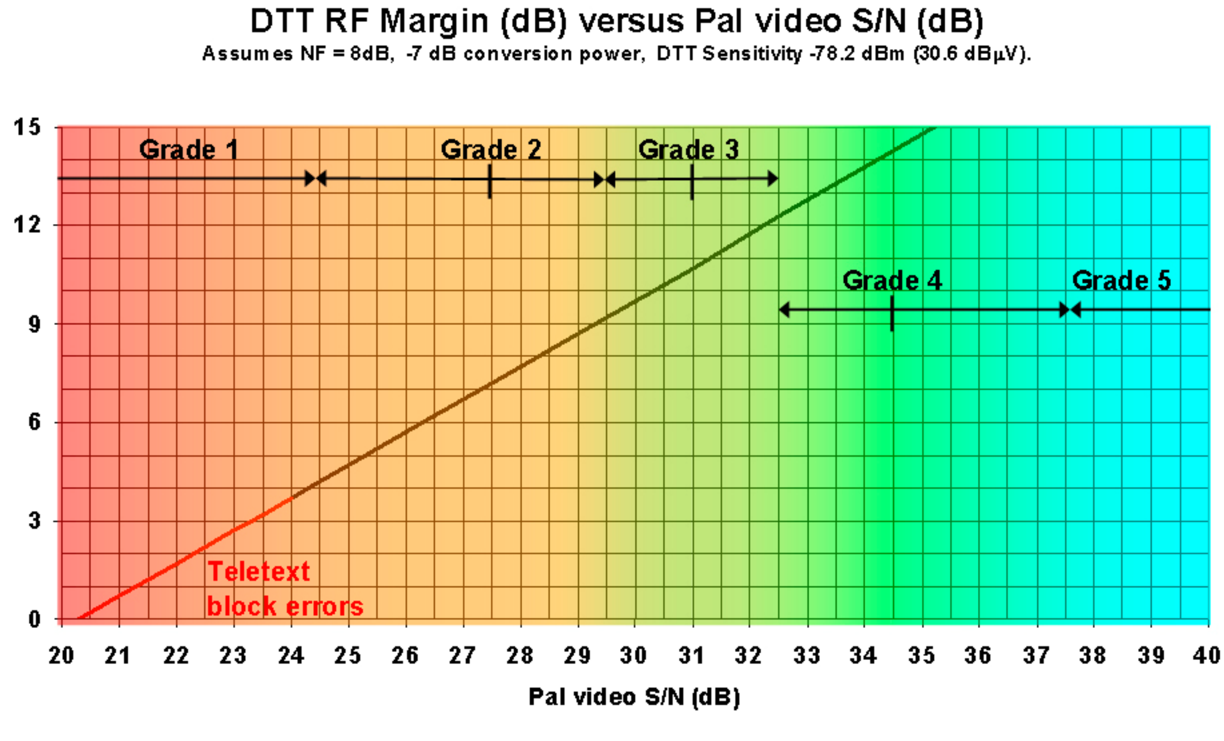

Figure 1: Existing analogue picture quality and future digital quality

Figure 1 shows us that the ‘just served’ level for existing analogue TV services equates to a future digital quality level of about 10 dB RF margin. The teletext test that this paper describes equates to a picture grade of about 1.5 or about 3 to 4 dB RF margin. Although there is still some RF margin, it is lower than the ‘just served’ analogue level. The teletext test is therefore a guide for viewers in that they *do* need to seek professional advice. The colours of Figure 1 can also be thought of as a guide in that the deeper the colour red, there is a greater probability of reception problems post DSO.

[2] This is the same overall coverage for public service digital transmissions, but not necessarily on a household for household or even TV set for TV set basis.

There are a number of assumptions in calculating these relationships and there are some caveats for some postcodes. These will be considered in detail; nevertheless it would seem that an aerial test based upon poor analogue picture quality and failure of a teletext test page will be a useful and simple guide that will be of benefit to the majority of viewers during DSO.

3 The main assumptions

3.1 The noise figure of digital receivers will be the same as that of analogue receivers.

This is a reasonable assumption.

3.2 The received digital signal level post DSO will be at a known level, relative to the received analogue signal level pre DSO.

This would be almost guaranteed if the only change were to be a change of transmission modulation type from analogue to digital with a relative power level[3] of –7 dB. There may be a small number of transmitter sites where this power relationship is different. Also, frequency plans may mean a change of UHF channel, which could introduce uncertainties. If there are only slight changes of UHF channel then these uncertainties may be reduced by viewers checking their analogue reception over a range of channels. The worst scenario is if DSO involves a change of channel to a different antenna group. It is then more probable that a receiving antenna[4] upgrade would be required. Such situations however will be known and publicised.[5]

3.3 The received channel conditions are noise limited i.e. Gaussian channel conditions.

In practice there are a number of factors that can affect reception. These include co-channel interference, multipath or echoes (often called delayed image or ghosting) and local sources of interference from ignition systems, switches and thermostats (generally called impulsive noise). Often the signal at the edge of a service area is interference limited or may suffer time varying (weather dependent) interference from distant sources. Analogue and digital signals behave quite differently when such interference is present. Generally, digital signals are more robust, but high levels of any interference can eventually ‘crash’ a digital signal. Therefore, an additional safety factor or ‘digital margin’ is generally required. The starting point is usually taken as the minimum receiver sensitivity (or input C/N ratio) required for the quasi-error-free (QEF) condition. Planners already take into account known sources of interference. In addition they allow a generous 3dB margin for multipath plus a, maybe not so generous, 1 dB margin for man-made noise. An overall margin of 6 to 10 dB is considered by some to be reasonable. Aerial installers generally aim to achieve greater than 10 dB margin for new installations.

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[3] How the power of analogue and digital signals are quantified is discussed later.

[4] In ‘technical speak’ the convention is to call an “aerial” an “antenna” and this will be followed for the technical discussions.

[5] The ‘aerial test’ is one of many DigitalUK ‘tools’ that supplement the postcode database.

4 Picture quality and RF signal level in general

The actual signal level arriving at the receiver can be calculated (see Appendix A) if the available field strength is known. The following factors are relevant:

- The transmitted power.
- The transmitting antenna gain and height.
- The propagation path (distance, terrain, local shadowing and other location losses).
- The receive antenna gain and height.
- The downlead loss.

Broadcasters know about the first three factors (excluding local conditions) and provide sufficient field strength within a service area for satisfactory reception to be possible. With assumed average values for the last two – often referred to as the 'aerial installation', a postcode guide regarding reception can be published. This is a simplification as there are a number of variables which complicate matters. The coarse terrain database used for calculations may not fully take into account local 'clutter' around the receive antenna and there can be other significant variations within a postcode area such as height and shadowing. The planers also have to consider abnormal propagation conditions due to weather that may mean an increase in interference from distant sources. The aerial installation may be below average or be more complex, with the received power being split to multiple TV sets within a household.[6] Older installations may also have poor quality coaxial cable and components which are far more susceptible to the ingress of local interference than their modern counterparts. The advantage of an on-screen indicator test is that most of these factors and variables are already included.

An estimate of the signal level arriving at the receiver input for an analogue transmission can be determined from the picture quality or video signal-to-noise ratio[7]. A BBC report [1] derives the relationship:

$$\text{Video S/N ratio (dB)} = \text{RF C/N ratio (dB)} - 8.047\ \text{(dB)} + 0.6\ \text{(dB)}$$

Some details of this derivation are outlined in Appendix B.

It is proposed that post DSO, DTT will be transmitted at a power level –7 dB relative to that of existing analogue transmissions. Therefore an estimate can be made of the digital signal level that will arrive at the receiver input post DSO.

There is a minimum signal level or sensitivity requirement for a digital receiver to work. This is –78.2 dBm (30.6 dBμV into 75 Ω) and is derived in Appendix C. The actual digital signal has to be greater than this minimum level by a reasonable RF margin in order for digital reception to be reliable.

Using these relationships then the future digital RF margin can also be plotted as a function of the existing analogue signal strength and corresponding video signal-to-noise ratio. This is shown in Figure 2 below.

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[6] Communal systems to multiple dwellings may be even more complex and include channel amplifiers. They are not considered here.

[7] We will see later that teletext errors are related to the video signal-to-noise ratio.

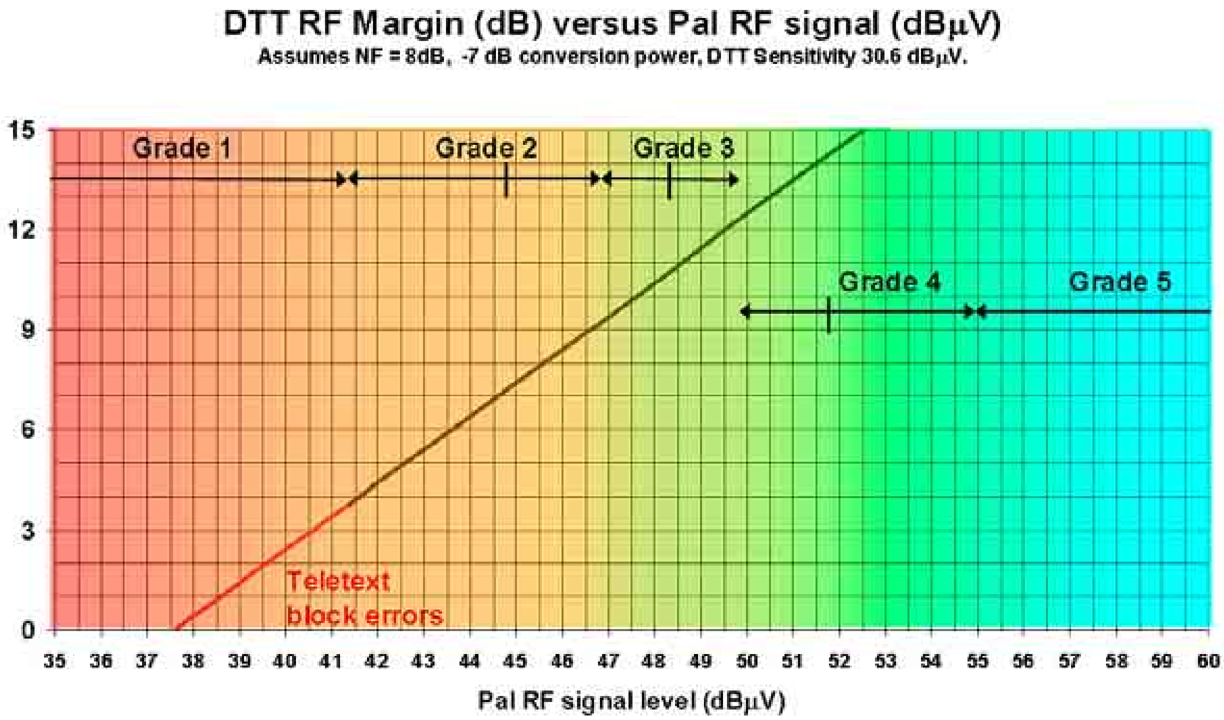

Figure 2: Existing analogue signal level and future digital quality

5 Analogue picture quality

The original idea for an aerial test was based upon the amount of picture noise that a TV set produces under weak signal conditions. Picture noise can be graded according to the CCIR five point impairment scale.

Grade	
5	Imperceptible
4	Perceptible but not annoying
3	Slightly annoying
2	Annoying
1	Very annoying

Table 1: CCIR Impairment Scale

A BBC report [2] details the relationship between subjective grade and the type of picture noise (called VSB noise) that a TV set produces under weak signal conditions. This report also compared VSB noise impairment with white noise impairment and concluded that VSB noise is about 2 dB less objectionable. The data presented in [2] has been re-analysed using the same analysis technique (details are given in Appendix D) and re-plotted with more modern tools.
If the subjective trend is plotted with a linear vertical axis representing CCIR grade then an S shape curve results and this is shown in Figure 3 below.

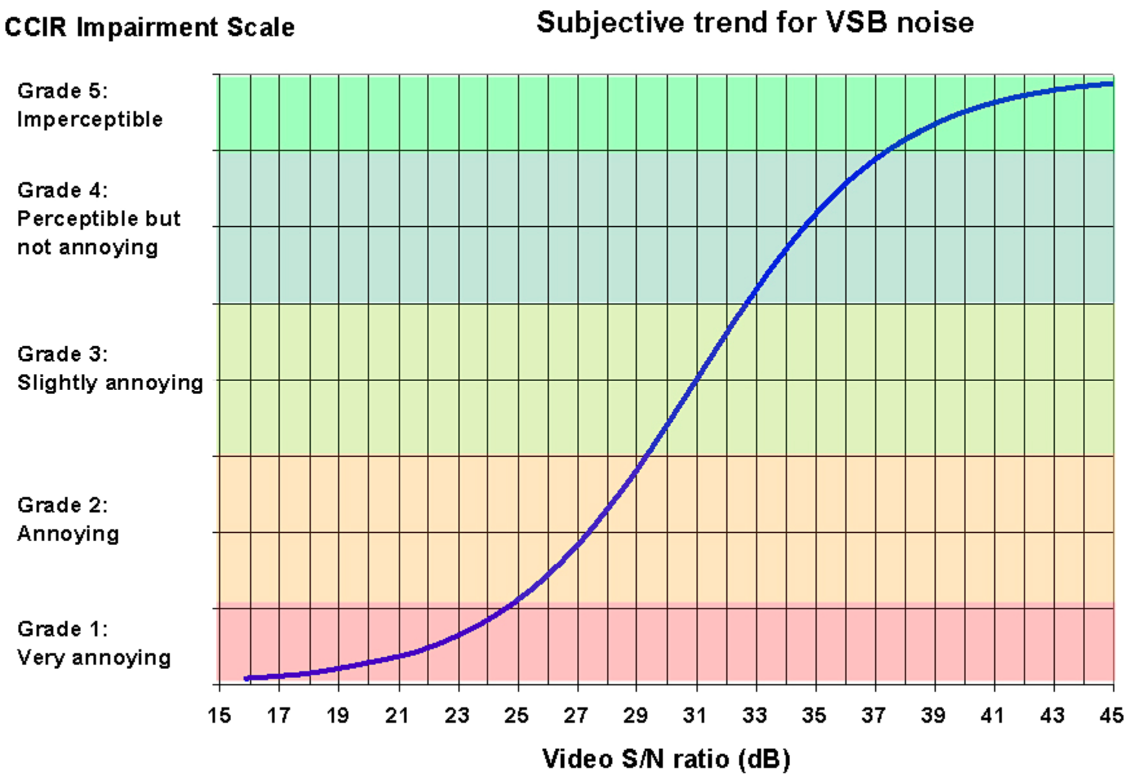

Figure 3: Subjective trend for VSB noise

Alternatively, data can be presented in the form of a table as shown below. Also included in Table 2 are 'half grade' scale points which represent the boundary point between grades.

Grade	Comment	Video S/N (dB)
5	Imperceptible	>37.5
4.5		37.5
4	Perceptible but not annoying	34.5
3.5		32.5
3	Slightly annoying	31
2.5		29.5
2	Annoying	27.5
1.5		24.5
1	Very Annoying	<24.5

Table 2: Analogue picture grades

The subjective results above are the mean scores from several observers. There will be some spread of opinion. Self assessment of picture quality for any individual viewer is not easy especially if there is no reference for comparison.

To aid self assessment of picture quality an experimental test logo was developed in order to help viewers make this judgement, but this still required the viewer to assess the visibility of a logo. A small in-house trial with BBC staff volunteers was done, but the results showed too much spread to proceed.

A further idea suggested, which showed greater promise, was that a 'reference' picture or pictures could be used as a guide. The following pictures are an example of how this may help.

Grade 5 **Grade 2**

Figure 4: Example representative pictures

A number of issues arise. The most obvious being that these are still pictures, whereas TV pictures in general are moving pictures. Even if the TV pictures are not moving, impairment such as noise will always have some temporal characteristic or 'twittering'. So in order to be representative, a number of still pictures with varying level of impairment have to be subjectively compared with a reference grade 2 TV picture (video S/N = 27.5 dB).

Another issue that has arisen with such degraded still pictures has been resolution and reproduction. The granular noise-like degradation places severe demands upon the digital processes involved in storage and reproduction of these images. Unexpected effects often surface. Indeed, this very paper will be converted to 'pdf' format. If the reader prints the pictures in Figure 4, the results will probably not be 'as intended for use'.

Despite these difficulties, such representative pictures may be of benefit to viewers and DigitalUK could add this technique to their DSO 'toolbox'. However, it was clear that an objective test would be far better.

6 The idea of using teletext as a test signal

Teletext was developed as a way of transmitting additional information within an analogue TV service. A full specification is in EN 300 706 [3]. A brief technical description, which may be useful, is given in Appendix E.

Early field trials [4] showed that teletext could be received at field strengths as low as 54 dBμV/m. From the example given in Appendix A and assuming nominal installation parameters, this is equivalent to a receiver RF input level of about –68.8 dBm. If we assume DTT can be received with RF input levels down to –79.5 dBm (the details are given in Appendix C), then the implication is that DTT is about 10.7 dB more robust than teletext at the point of failure. It is proposed that DTT will be transmitted at a power level –7 dB relative to that of existing analogue transmissions. Therefore, a test based upon the failure of a teletext page would indicate that post DSO DTT signals could be received with a margin to failure[8] of 3.7 dB.

The idea of using teletext as an on screen indicator test looks reasonable. However, later work [5] showed that teletext reception can be much poorer in the presence of multipath interference[9], whereas DTT reception is hardly affected by this. The reason for this poorer performance of teletext is that multipath can cause intersymbol interference, especially if the echo delay is a multiple of the bit repetition period (≈ 144 ns).

[8] This safety factor is often called 'digital margin', 'noise margin' or just 'margin'. It is important to know which reference or stating point (0dB) is being used. Planners tend to use the minimum working level, whereas for test and measurement the point of 'failure' is generally used. An analogy is the 'top' and 'bottom' of the 'digital cliff'. The difference between the two is about 1.3 dB.
[9] Sometimes called delayed image, echo or ghost interference.

7 Required features of a teletext test signal

If we want to use teletext as an on-screen test there are a number of features that we would like:

- Any data sequence should be as tolerant as possible to multipath.
- Any errors should be obvious and clearly visible.
- A test page should not be updated by the decoder otherwise errors may be corrected.

A teletext waveform that has the minimum number of data transitions is less likely to be troubled by intersymbol interference and hence show correlation between teletext reception quality and picture signal-to-noise ratio. In an eight-bit odd parity system it is possible to have a maximum of eight consecutive 0s or 1s, spread across two consecutive characters. By alternating a character with seven consecutive 1s with its complement, it is possible to generate a square wave with a period of sixteen bit periods. In the teletext standard there are four ways of doing this, but the most suitable for this application is the bit sequence of 00000001 11111110 which are the two data bytes associated with the NUL and ■ characters. NUL is a control character with no effect in teletext and therefore can be thought of as a space; it is reserved for compatibility with other data codes.
■ is an alphanumeric character which can be thought of as a block, but it is not a graphic. On a TV screen, characters are displayed in colour on a black background. The colour of the ■ character is actually white but in the text of this paper there is little choice than to incorrectly show it as black on white! Fortunately, if the ■ character is in error and gets displayed as anything else, (we will see later that the most likely change would be to a space) this should be a very obvious error to see.
Thus if the above sequence is repeated, a complete test page can be assembled and it would be seen on a TV screen as follows:

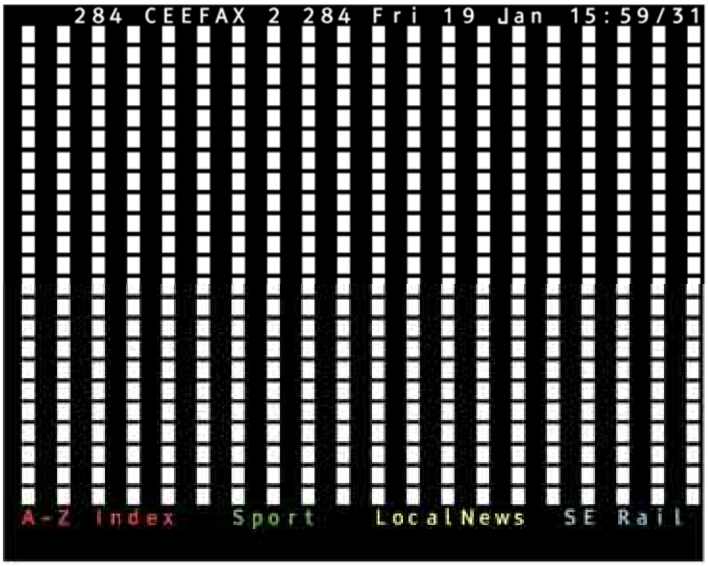

Figure 5: Example teletext test page (no errors)

8 Behaviour of a teletext test signal with errors

We now have to consider the effects of noise / interference on this test page and whether we have achieved the required features that we want. A theoretical analysis considering the probability and effect that errors will have on this test page is given in Appendix F. This shows that upon first download (with bit errors), the most likely effect is that blocks will be displayed as spaces i.e. blocks will disappear. Missing blocks should be quite easy to see and count. There is a lesser probability that spaces and blocks may be displayed as erroneous characters. Intersymbol interference due to multipath may have a greater effect on bytes other than the space and block bytes. Remember that it is only the space and block bytes that have been specifically selected to have the minimum number of data transitions (00000001 11111110). If multipath upsets the clock run-in, it is likely that that a whole row may not be decoded at all due to failure of synchronisation. Instructions would have to be given about ignoring any missing rows.

If the teletext test page is received with errors then it could be seen on a TV screen as follows[10]:

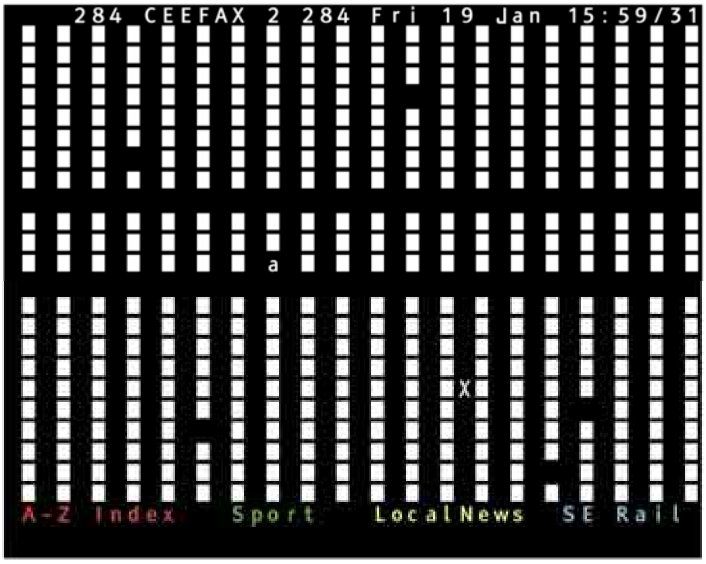

Figure 6: Example teletext test page (with errors)

Figure 6 above shows many of the effects that may occur if reception is poor. The missing blocks and the missing row are very obvious errors. From the theoretical analysis in Appendix F we can relate the number of missing blocks to the most likely video signal-to-noise ratio. This is shown in Figure F5 in Appendix F, but is also reproduced below for convenience.

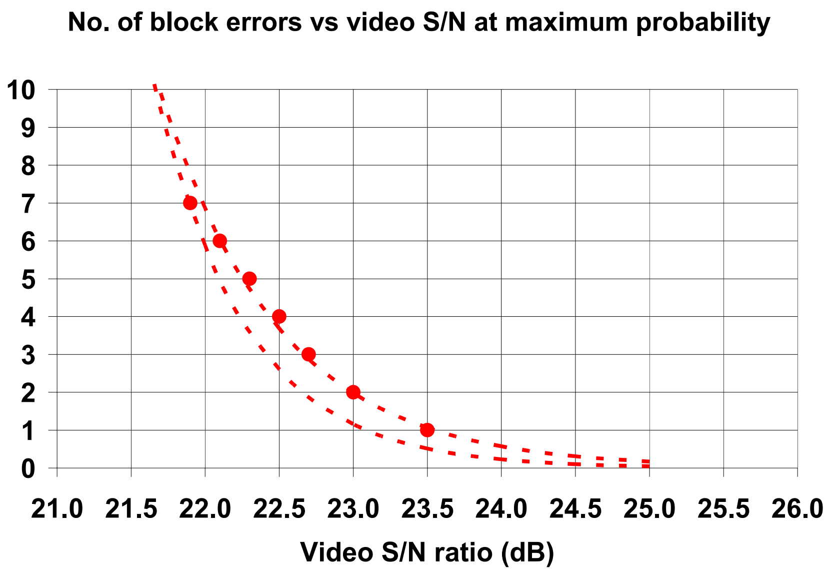

Figure F5: Maximum probability of N blocks being wrong [from Appendix F]

For this example and with reference to Figure 1, we could conclude that the likely digital margin is only about 1 or 2 dB.

[10] This is only a representation as it is impossible to predict random effects.

9 Page updating and caption

We do not want the decoder to update this test page; otherwise any errors upon first reception may be subsequently corrected. If this data is transmitted alternately with different data then the decoder accepts that the associated page has been changed since the previous transmission. A second set of data is quite convenient too, because some instruction or caption is required in order to give guidance about the overall use of the test. Thus the complete test may be realised as a sequence of two sub-pages with different data and repeated with a suitable repetition period. For example: Caption, Test, Caption, Test, etc. For this sequence, there is no update of the same data[11]. It is desirable to ensure that the first sub-page (the caption) is displayed for sufficient time for it to be comfortably read. It may be necessary to repeat the caption data in order to achieve this. It does not matter if the caption data is repeated; in fact this would be desirable as any errors within the caption text are likely to be corrected. A different sequence of transmission[12] for the pages may be: Caption, Caption, Test, Caption, Caption, Test, etc.
The caption text that gives instructions about the test[13] is shown below:

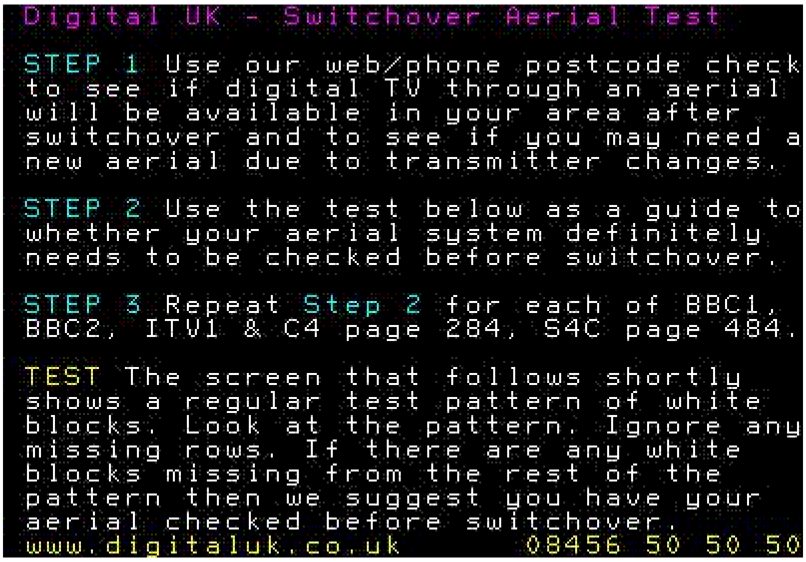

Figure 7: Example caption sub-page text

10 Practical tests and trials

A number of laboratory tests have been done in order to validate the theory outlined above. Detailed results have been presented to the Digital Reception Prediction Group run by DigitalUK and only a summary will be presented here.

10.1 Block errors versus video S/N ratio

Calibrated levels of additive white Gaussian noise (AWGN) were added to a composite video signal and the degraded signal applied via the video input to a number of TV receivers. Results were remarkably consistent and showed good agreement with Figure 5F.

[11] Some decoders may store sub-pages if they are numbered differently. These sub-pages should be numbered the same – probably zero or one, so they are not recognised as a sequence.
[12] The actual sequence and timings will be determined by the individual broadcaster with due regard to other teletext data within the magazine.
[13] This is subject to review and may change.

10.2 Block errors versus RF C/N ratio

Calibrated levels of AWGN were added to a grade 5 PAL RF signal and the degraded signal applied via the RF input to a number of TV receivers. Results showed good agreement with Figure 2. The spread of results was slightly greater than the results of (10.1) possibly due to slight differences of IF filtering.

10.3 RF performance with multipath

Tests were made as (10.2) above but now a single echo was added to the RF signal. Different echo amplitudes, delay and phase were applied in order to establish the resilience of the test page. There are a number of variables to consider and the types of transmission we are considering respond in different ways. Teletext is particularly sensitive to the phase and delay of echoes corresponding to multiples of the bit repetition period (≈ 144 ns). The following table gives an indication of the relative performance[14] of the different transmission types in the presence of multipath.

Echo delay	Analogue pictures	Teletext test	DTT
Very short echoes (< 1 μs)	Good / Fair	Fair, but some echo phases – Bad	Excellent
Short echoes (1 to 10 μs)	Fair / Bad	Good / Fair	Excellent / Very good
Long echoes (10 to 20 μs)	Bad	Good	Good

Table 3: Performance comparison with multipath impairment

From the tests that were made it was concluded that:

- The test page does have up to 6dB more resilience compared to the index page.
- For most cases of expected multipath degradation (to grade 3) the test page is reasonably resilient.
- There are very few combinations of echo delay and phase where the teletext performance is significantly worse than that of the analogue picture and future DTT performance.
- The accuracy of the test page is reasonable for the majority of reception conditions.

10.4 Off-air RF performance.

Broadcast signals were received ‘off-air’ and the received signal level was attenuated in order to determine the relationship between receiver sensitivity and number of block errors on the teletext test page. Results were obtained for a number of receivers for each of the four main analogue TV services broadcasting on different channels. These results showed the greatest spread but were in general agreement with Figure 2. The average of the results indicated that overall receiver sensitivity is slightly better than Figure 2, which implies that receiver noise figures are slightly better than the assumed value of 8 dB.

10.5 DSO at Whitehaven.

This test was available for DSO at Whitehaven in October 2007. DigitalUK produced the leaflet given in Appendix G for Whitehaven viewers. Market research after DSO was very favourable. Viewers preferred the objective teletext test rather than any subjective assessment. In particular it was appreciated that a simple self assessment test could provide reassurance.

[14] On a 5 point scale: Excellent, Very good, Good, Fair, Bad.

11 Recommendations resulting from practical tests

Originally it was thought that the threshold for failing the teletext aerial test would be for four or more block errors within the test page. In order to compensate for an apparent slight increase in receiver sensitivity it is recommended that the threshold should now be set to one or more (i.e. any) block error.

12 Risk factors

By having a very objective test such as this teletext test page could raise a number of perception issues with viewers. They may interpret this test as a definitive answer to the question "is my aerial system good enough for digital?" and expect 100% satisfaction post DSO if they pass[15].

If a high failure threshold were set, then more viewers would probably get an aerial upgrade. Fewer, if any, would then have any problems post DSO. However, many viewers may have upgraded their aerial unnecessarily. Criticism could then be vehement and hard to defend.

It would be irresponsible to advise viewers to upgrade their aerial system if this was not necessary. On the other hand by erring to a lower threshold level such that only those viewers whose signals are dire are advised to get their aerial system checked, may mean that some viewers are not 100% satisfied with their reception post DSO. It would seem that this is a no-win situation.

It would be all too easy to do nothing. However, that would not help the majority of viewers decide whether they really do need to improve their aerial installation or give any reassurance.

The 'low threshold' or 'wait and see' approach is preferable for these borderline cases. For viewers who are not 100% satisfied post DSO the situation should be readily resolved by the viewer getting an aerial upgrade after all.

From the work done so far it would seem that this teletext test will definitively identify a large subset of those aerial installations that will ***not*** be good enough for digital. As such, the test should be a useful *guide* as to whether viewers should *seek professional advice*. Clearly, any publicity associated with this test will require some thought in order to achieve the correct message.

13 Conclusions

In preparation for DSO a teletext based test of the signal quality from an aerial has been developed and presented. Market research indicates that this simple and cost effective test will benefit the majority of viewers during DSO.

Where this test is suitable viewers can self-assess the picture quality of their analogue reception and use this teletext aerial test. The received signal strength needs to be at a level that is equivalent to an existing analogue picture level of better than Grade 2. A reference (still) picture may be useful to assist viewers make this judgement, although most viewers may prefer to use the more objective teletext test.

Risk factors have been considered, mainly to avoid viewers unnecessarily upgrading their aerial pre-DSO. It is preferable that the pass 'threshold' of the teletext test is quite low. This means that if the teletext test fails, viewers definitely need to seek further professional advice. Passing the teletext test means that there is some digital margin but it should not be taken as a guarantee that digital reception will be 100% reliable post DSO because it is impossible to predict the effect of any time varying local interference. A small number of viewers may find that post-DSO an aerial and / or cable upgrade is required after all, despite the teletext aerial test having been passed.

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[15] 100% satisfaction is an impossible promise. Time varying interference from local and distant sources (these may be weather dependent) can have a detrimental affect on normal reception.

This test is not suitable for some switchover scenarios but these are known and will be publicised by DigitalUK. Viewers should check their postcode database as a first step or seek further advice if they are unsure. Where the test is applicable and viewers have sought further advice it has been appreciated that a simple self assessment test can provide reassurance.

14 Acknowledgements

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16 Appendix A: The RF signals from an antenna

The level of an analogue TV signal is quantified by measuring the power of the vision carrier during the synchronisation period or so called peak-sync-power (PSP). Note that digital signals are quantified by measuring their continuous power. The units of power are watts (W), but it is conventional to express received power as a logarithmic ratio relative to 1 mW, such that 1 mW = 0 dBm. TV receivers usually have a nominal input impedance of 75 Ω. It is universal practice within the receiver industry to work with 75 Ω impedances and express this signal level as a logarithmic voltage ratio relative to 1 μV, such that 0 dBμV across 75 Ω = –108.75 dBm.

The convention for both analogue and digital signals is to call these signals the carrier[16] power (*C*). Fundamental theory shows that at the input of a receiver, the carrier power is given by:

$$C = \frac{E^2 (1.64) G L \lambda^2}{480 \pi^2} \quad \text{watts}$$

where *E* = field strength (V/m),
G = receive antenna gain relative to that of a dipole,
L = feeder factor,
λ = wavelength (m).

Note: Parameters are in SI units or ratios are linear.

Typically, the product GL equals 5 (7 dB). For example in dB, where we can add contributions: antenna gain = 10 dB, feeder factor = – 3 dB (or 3 dB loss).

For example, if E = 54 dBμV/m, GL = 5 (7 dB), λ = 0.55 m (frequency = 546 MHz which is equivalent to UHF channel 30), then C = –68.8 dBm (40 dBμV).

16.1 Ready-reckoner for 75 Ω systems

To convert a signal level expressed in dBμV to dBm, *subtract* 108.8.
e.g. 40 dBμV – 108.8 = –68.8 dBm.

To convert a signal level expressed in dBm to dBμV, *add* 108.8.
e.g. –68.8 dBm + 108.8 = 40 dBμV.

16.2 Antenna noise

A simplification for UHF antennas pointing towards the horizon is to assume that the antenna noise temperature is equal to the reference temperature[17] of 290 K. We will apply this here. Sadly, there are indications that man-made electromagnetic noise pollution at UHF is increasing the antenna noise temperature well above 290 K [9]. For this application however, this has less relevance as we are essentially comparing analogue with digital reception. The antenna noise temperature will not change due to DSO! The available noise power from the antenna is taken as:

$$N = kToB \quad \text{watts}$$

Where: k = Boltzmann's constant (1.38 × 10–23 J/K)
To = Reference temperature (290 K)
B = System noise bandwidth. (Hz)

Note: Parameters are in SI units. For DVB-T, N = -105.2 dBm (3.6 dBμV).

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[16] Some people do not like this convention for digital signals because a digital signal has numerous carriers. However, the overall power of a digital signal may be thought of as a centre carrier with very complex sidebands!

[17] 290 K is the reference temperature used when specifying receiver noise figure.

17 Appendix B: Noise in a PAL-I (analogue) system

The first thing to define when talking about noise power is the relevant noise bandwidth (B). For a PAL-I analogue TV receiver the noise bandwidth for an IF filter with an ideal Nyquist slope is derived in [1] and is 5.0833 MHz[18]. This strange figure is due to integrating the non-rectangular response of the analogue receiver Nyquist filter essential for dealing with VSB TV transmissions. This means that the thermal noise floor (N) is –106.9 dBm. This determines the RF carrier-to-noise ratio (C/N) at the input of a receiver. This in turn is related to but not the same as the analogue picture or video signal-to-noise (S/N) ratio. The full details of this relationship are derived in [1].

Theory shows that for a PAL-I TV transmission the video S/N ratio at the output of an ideal demodulator is less that the RF C/N ratio by 8.047 dB. Relevant parameters in deriving this relationship are:

- PAL-I vision carrier modulation depth for black and white video levels are: 76% and 20% respectively.
- Video S/N is defined as the ratio between the voltage transitions from black to white level, to the root-mean-square (rms) noise voltage. For a standard 1 V p-p composite video signal the transition from black to white level is 0.7 V.

It should also be noted that the power spectral density of the PAL-I demodulated noise is not flat (white noise), but gradually reduces over the range 1.25 to 0 MHz by a maximum of 3 dB. This noise spectral density is called vestigial sideband (VSB) noise and is a fundamental consequence of the VSB modulation that is used for analogue TV transmissions. Indications are that VSB noise is subjectively 2 dB less damaging than white noise [2].

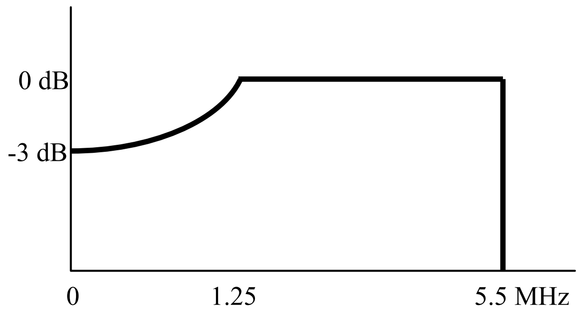

Figure B1: Noise spectral density from an ideal PAL-I demodulator

When measuring video S/N ratio according to CCIR rec. 567 [6] a 5 MHz low-pass-filter is introduced. This filter is quite 'soggy' with a response of –3 dB at 5 MHz. As a consequence some of the VSB high frequency noise (from the ideal demodulator) is removed, so a correction of 0.6 dB has to be made for this. [19]

The relationship between RF C/N ratio and the video S/N ratio for a PAL-I system is taken as:

Video S/N ratio (dB) = RF C/N ratio (dB) – 8.047 (dB) + 0.6 (dB)

[18] Modern surface acoustic wave (SAW) filters approximate this response. Their actual noise bandwidth is not significantly different, so this theoretical figure is used.

[19] This correction factor means that no further correction is required for practical TV demodulators which are unlikely to have a flat video response to 5.5 MHz.

18 Appendix C: A Noise model for DVB-T

A useful model for calculating the noise performance of a DVB system was first proposed by the author in 1998 [7] and has subsequently been widely adopted. It is illustrated in Figure C1 below.

The terminology used is as follows:

C =	Signal input power (W) of the DVB-T ensemble
k =	Boltzmann's constant (1,38 × 10^{-23} J/K)
To =	Reference temperature (290 K)
B =	System noise bandwidth (7,61 MHz)

The model comprises the following representative components.

- A front-end stage with system noise factor F and 'perfect' automatic gain control (AGC). The action of the AGC is to provide a power gain of 1/C, and so the tuner output is unity as a consequence.
- An excess noise source of power P_x. Note that, by normalising the carrier power to unity at the tuner output, the relative value P_x can be added directly at this point.
- A practical but unimpaired demodulator; that is, a demodulator with a fast channel equaliser and a consequent implementation margin (IM) of 2 dB.

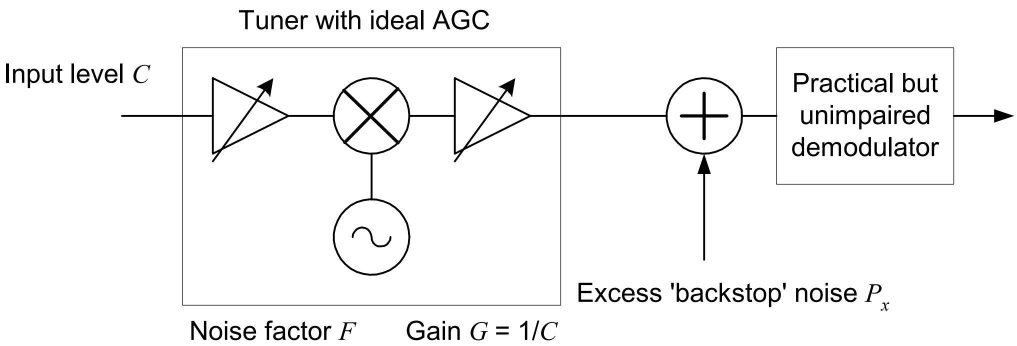

Figure C1 – Noise model

Note that the relative excess noise Px is the sum of contributions from all stages in the signal chain. Significant contributions could include:

- Receiver local oscillator phase noise.
- Quantisation noise introduced by the demodulator analogue-to-digital converter.
- "Backstop" thermal noise introduced after the gain-controlled stages in the receiver.
- Transmitter intermodulation products.

The carrier-to-noise ratio is C / kToB at the tuner input, and CG / kToBFG at the tuner output. Hence the carrier-to-noise ratio at the input to the "practical" demodulator is given by:

$$C/N = CG / (kToBFG + P_x)$$
$$= C / (kToBF + CP_x)\text{ , since } G = 1/C.$$

The C/N ratio at the demodulator for a minimum required level of performance (R_{DQEF} say) will depend upon the theoretical performance for a particular modulation mode and an implementation margin (IM) as specified above. A practical formula for R_{DQEF} in dB is given below:

$$R_{DQEF}\text{ (dB)} = \text{Theoretical C/N (dB)} + \text{IM (dB)}$$

For the modulation mode that will be used post DSO in the UK[20], the minimum required C/N ratio at the demodulator (R_{DQEF}) is taken as 18.7 dB. Note this not the C/N ratio at the receiver input. The value of C for this level of performance is the sensitivity (P_{in}). Re-arranging the above equation gives this:

$$P_{in}(sensitivity) = \frac{KT_0BFsys}{\left({}^{1}\!/\!{}_{R_{DQEF}} - Px \right)}$$

Note that the C/N ratio at the receiver input for this performance level (A_{RQEF} say) is then:

$$\frac{P_{in}(sensitivity)}{KT_0BFsys} = \frac{1}{\left({}^{1}\!/\!{}_{R_{DQEF}} - Px \right)}$$

All the above parameters are taken to be linear quantities. In practice, it is more usual to express C/N, Pin, G, F, Px, R_{DQEF} and A_{RQEF} in dB.

A practical formula for the sensitivity (P_{in}) in dBm is given below:

P_{in} (dBm) = A_{RQEF} (dB) + Noise floor (dBm)

Where A_{RQEF} is the C/N ratio in dB at the receiver input that provides the minimum performance level. Note this will be slightly greater than R_{DQEF}, especially so for high capacity modes.

18.1 Practical values

For the modulation mode that will be used post DSO in the UK, the minimum required C/N ratio at the receiver input (R_{DQEF}) and hence input power P_{in} (dBm) is calculated using the following parameters:

R_{DQEF} = 18.7 dB

Transmitter excess noise contribution = –34 dBc

Receiver excess noise contribution = –33 dBc

Therefore total excess noise contribution (Px) = –30.5 dBc

Therefore A_{RQEF} = 19.0 dB

Thermal noise (kTB) = –105.2 dBm

Receiver noise figure = 8.0 dB

Therefore the noise floor referred to the receiver input = –97.2 dBm

P_{in} = –78.2 dBm (30.6 dBμV into 75 Ω)

The above figure of –78.2 dBm is the minimum receiver sensitivity for the quasi-error-free (QEF) condition. It is useful to know the level at the point of 'failure'. This is 1.3 dB lower at –79.5 dBm. This is the level where picture artefacts start to appear. An analogy is that the quasi-error-free (QEF) condition is at the 'top' of the 'digital cliff' and the 'failure' condition is at the bottom.

[20] This is: FFT size 8K, 64 QAM non-hierarchical constellation, 2/3 code rate and 1/32 guard interval.

19 Appendix D: Analysis of subjective data

The method of analysis for subjective test results is suggested in CCIR Report 405-5 [8].

Grade	
5	Imperceptible
4	Perceptible but not annoying
3	Slightly annoying
2	Annoying
1	Very annoying

Table D1: CCIR Impairment Scale

A simple transformation is applied to the mean scores to give an impairment parameter I. When log I is plotted against the logarithm of the objective measure of impairment, a straight trend line is generally obtained. Note that the objective measure is often a ratio (e.g. video signal-to-noise) express in dB so a linear dB scale results. Values of I are obtained as follows:

For subjective tests on a scale of 1 to 5 grades as detailed above in Table D1, the mean score Um is obtained.
The scale of values is normalised by taking a continuous variable u, such that:

$u = (Um-1)/4$ Then: $I = (1/u)-1$

Often, specific values for Um or I are known or want to be obtained. A spreadsheet such as Excel can obtain a trend line using the method of 'least squares' and it is easy to see how known data fits this analysis method[21].

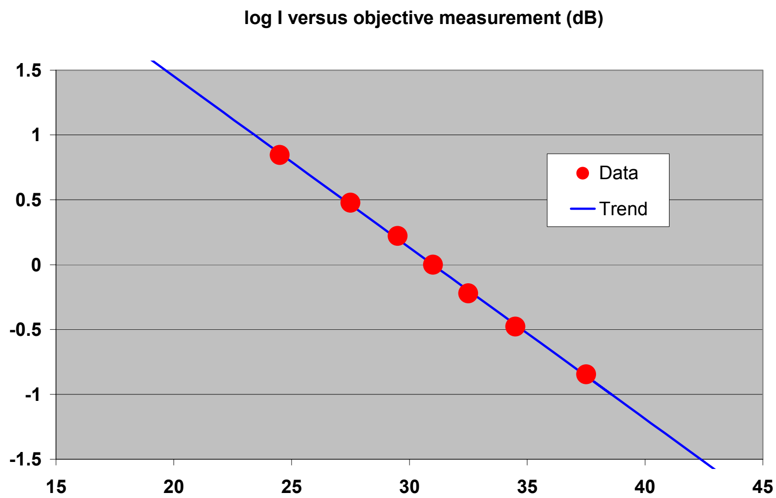

Figure D1: Analysis of subjective data from [2]

If the subjective trend is plotted with a linear vertical axis representing CCIR grade (Um) then an S shape curve results and this is shown in Figure 2 in Section 5.

[21] This method of analysis does come with a warning. Caution is required if known data is sparse or has a high degree of scatter. Also significant extrapolation outside of the range of known data is likely to be unreliable.

20 Appendix E: Teletext – a brief description

Teletext data is transmitted on unused lines in the field-blanking interval. Permitted lines are 6 to 22 inclusive and 318 to 335 inclusive. A two-level non-return-to-zero (NRZ) system is used. The data 0 value is black level ±2% and data 1 value is 66±6% of peak white. For a standard 1 V p-p composite video signal the transition from black to white level is 0.7 V. Thus the nominal data amplitude is 462 mV. The data rate is 6.9375 Mbits/sec (444×line-rate) and the waveform is shaped so that the spectrum is substantially skew-symmetrical about 3.46875 MHz (half the bit rate). This means there is minimal energy above 5 MHz. One line of transmitted data represents one row of displayed text.

Each displayed page consists of 24 rows: the page header line with the page number, title, and clock time followed by 23 rows each of which can have 40 text or graphic symbols. The pages are identified by a one-digit magazine number followed by a two-digit page number. The page header carries the page number and each row carries a magazine number and row address. Transmission of a page starts with the page header; all following rows with the same magazine number relate to that page, until the next page header with the same magazine number. Rows of a page are not necessarily transmitted in order. Pages may be transmitted in any order, and rows from pages with different magazine numbers may be interleaved.

Each data line comprises 360 bits, which may be considered as 45 bytes. The first two bytes form a clock-run-in (2×10101010) and the third is a framing code (11100100). These three bytes thus have even parity. The fourth and fifth bytes are Hamming coded, carrying the three bits of the magazine number and five bits of the row address. The remaining 40 bytes carry the text for display as seven-bit codes with an odd parity bit. The bits are transmitted in numerical order from bit 1 to bit 8 (the parity bit). Some of the transmitted characters are control codes governing text/graphics mode, display colour, flash on/off, etc.; these characters have both bit 6 and bit 7 as 0. The control characters are not displayed; all other characters except the space character 00000100 should produce a displayed symbol.

The failure of a parity check causes the corresponding character to be displayed as a space. If the failure is caused by random interference, it is likely that the previously erroneous character will be correctly received next time the row is broadcast and the space will be filled in. However, correctly received characters are not overwritten with spaces if they are subsequently received with failed parity.

21 Appendix F: Teletext test page – probability theory

21.1 Probability of errors in a teletext test page

It is helpful to have an idea from theory of the probability of errors being visible in a teletext page. For an ordinary page this is rather difficult to quantify because bit errors do not necessarily result in displayed errors and displayed errors can be subsequently corrected by updating. The failure of a parity check causes the corresponding character (including a space character) to be displayed as a space. If the failure is caused by random interference, it is likely that the previously erroneous character will be correctly received next time the row is broadcast and the space will be filled in. Previous correctly received characters are not overwritten with spaces if they are subsequently received with failed parity. However, for a special test transmission we can ensure that our test data is not updated[22]. For a test page of rows of alternating control characters (spaces) and display characters (blocks) as described above, an analysis is possible. If a space or block is displayed where a space or block should be, we will call that condition "right" even though the actual character byte may be incorrect (have errors). The opposite we will call "wrong"

21.2 Probability of a byte being incorrect

If the probability of any single bit being in error is p, the probability of that bit being correct is $1–p$. The probability of an eight bit character byte being correct is $(1 – p)^8$ and the probability of an eight bit character byte being incorrect is:

$$1 – (1 – p)^8 \qquad \ldots(1)$$

This however is the total probability where any number of bits from one to eight could be incorrect. The dominant condition and the one that we are most interested in is that of a single bit error. This will result in a parity check failure and the corresponding character would then be displayed as a space. For our control characters (spaces) this condition is "right", whilst for display characters (blocks) this condition is "wrong". Hence, the general overview is that as the video S/N ratio degrades, errors start to make the blocks in the test page disappear. We need, however, a little more analysis to quantify this.

21.3 Probability that a display character (block) is wrong (P_d)

The probability that any number (N) of eight bits will be in error involves multiplying the probability that N bits will be in error with the probability that (8 – N) bits will be correct and with the combination ^8C_N, resulting in the general equation:

$$p^N \times (1 – p)^{(8–N)} \times {}^8C_N = p^N(1 – p)^{(8–N)}8!/N!(8 – N)! \qquad \ldots(2)$$

We have assumed the dominant condition is that of a single bit error i.e. any one of eight bits could be in error. Other conditions such as any two of eight bits and any three of eight bits etc., could be in error, are increasingly insignificant. Besides, any odd number of bit errors will result in a parity check failure and the corresponding character would then be displayed as a space. We can see how dominant the single bit error is by evaluating[23] the general equation (2) above, for the case when N = 1. It may be helpful to write this out in full:

$$p^1 \times (1 – p)^7 \times {}^8C_1 = p(1 – p)^7 8!/1!7! = 8p(1 – p)^7 \qquad \ldots(3)$$

We then compare the results from (3) with the results from (1) above. That is we are comparing the probability of only one of eight bits being in error with the probability of any number of eight bits being in error. The comparison is shown in Figure F1.

[22] The page data of special test rows is alternated with different data describing the test. So in effect, because there is no update of the same data, this amounts to a single transmission.
[23] The formula to do this is given later.

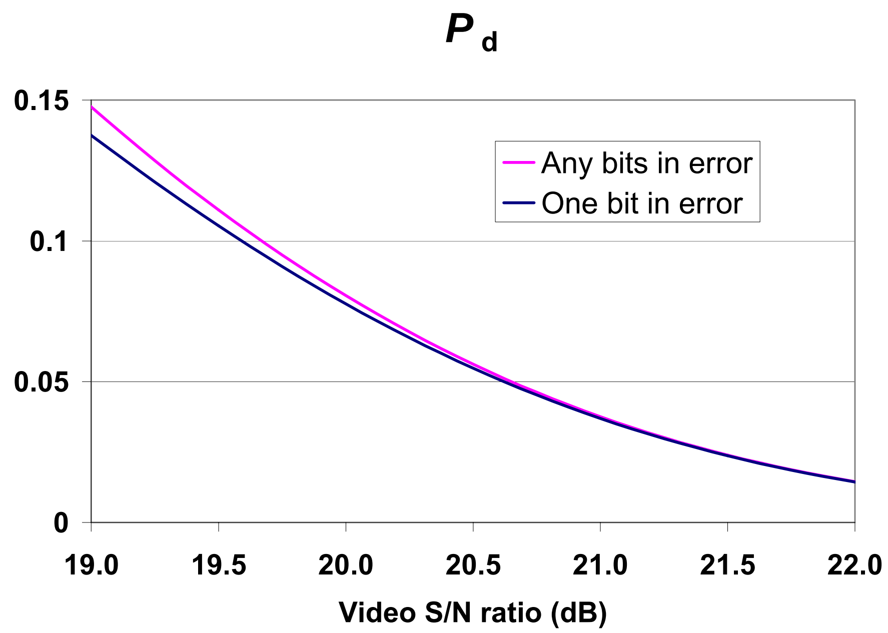

Figure F1: Probability that a display character (block) is wrong.

For video S/N ratios > 20 dB, the difference between any number of bits and only one bit of eight being incorrect is small enough to be ignored so we will take the probability that a display character will be wrong (P_d) as:

$$P_d = 8\, p(1 - p)^7 \qquad \ldots(4)$$

21.4 Probability that a control character (space) is wrong (*P*c)

Similar calculations to that for a display character apply to the control character. However, we can immediately see that it will be more 'robust' than the display character because a control character will be displayed "right" (i.e. as a space) if it is received correctly, or with one error, or with two errors that do not affect bits six or seven or both; three errors will be detected as even parity causing a space to be displayed (i.e. "right"), and higher numbers of errors can almost certainly be discounted.

The probability of two errors occurring in eight bits can be derived from the general equation (2) above and is:

$$p^2(1 - p)^6 8!/6!2! = p^2(1 - p)^6 28$$

However, only the combinations of two errors that affect bits six or seven or both result in the control character being "wrong". These combinations are:

a) When bit six and any one of six other bits (excluding bit seven) are in error.

b) When bit seven and any one of six other bits (excluding bit six) are in error.

c) When bit six and bit seven are both in error.

From a, b and c above, it would seem that there are (6+6+1) = 13 of these 28 ways when bits six or seven or both are in error. However, for the control character that is used (00000001), when bits six and eight are in error the result is 00000100, which is the space display character. Therefore only 12 of these 28 ways when any two bits in eight are in error will result in a control character being "wrong" (not being a space). The overall probability of a control character being wrong (P_c) is therefore:

$$P_c = (p^2(1 - p)^6 8!/6!2!)12/28 = p^2(1 - p)^6 12 \qquad \ldots(5)$$

This is evaluated and shown in Figure F2.

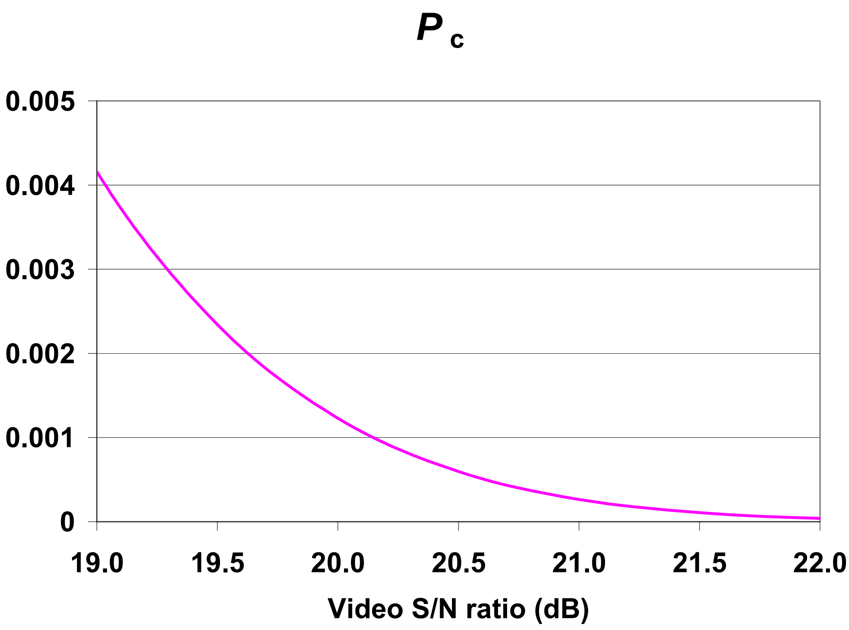

Figure F2: Probability that a control character (space) is wrong (P_c).

We see that P_c is very small. For a video S/N ratio of 20 dB it is about sixty times smaller than P_d. This confirms the general overview that as the video S/N ratio degrades and bit errors increase, the display characters (blocks) in the test page will start to 'disappear'. Existing spaces will tend to remain as spaces because the probability of any control characters (spaces) being wrong is far less.

21.5 Probabilities for blocks within the whole test page being wrong

There are 23 × 40 = 920 characters on a single page. For the test page we are considering, half of them (460) are spaces and half of them (460) are blocks. If the probability of a block being wrong is P_d, then the probability of it being right is $(1 – P_d)$. The probability of all 460 being right is $(1 – P_d)^{460}$ and the probability of any of the 460 being wrong is $1 – (1 – P_d)^{460}$.

However this is the probability of one or more (which is the same as any) blocks being wrong. It is worthwhile, for reasons we shall see later, to investigate the probabilities of any individual number (N) of 460 blocks being wrong (P_{Nb}). This involves multiplying the combination $^{460}C_N$ with the probability that N blocks will be wrong and with the probability that (460 – N) blocks will be right.

For N = 1, $P_{1b} = {}^{460}C_1 \times P_d^{\,1} \times (1 - p_d)^{459} = P_d(1 - P_d)^{459} 460!/1!459!$
For N = 2, $P_{2b} = {}^{460}C_2 \times P_d^{\,2} \times (1 - p_d)^{458} = P_{d2}(1 - P_d)^{458} 460!/2!458!$
For N = 3, $P_{3b} = {}^{460}C_3 \times P_d^{\,3} \times (1 - p_d)_{457} = P_{d3}(1 - P_d)^{457} 460!/3!457!$
For N = 4, etc.… up to:
For N = 460

If we add all of the above 460 probabilities together it will equal $1 – (1 – P_d)^{460}$, which is the probability of any block being wrong. This probability and a number of other examples where N blocks are wrong have been evaluated[24] and are shown in Figure F3.

[24] The formula is given later.

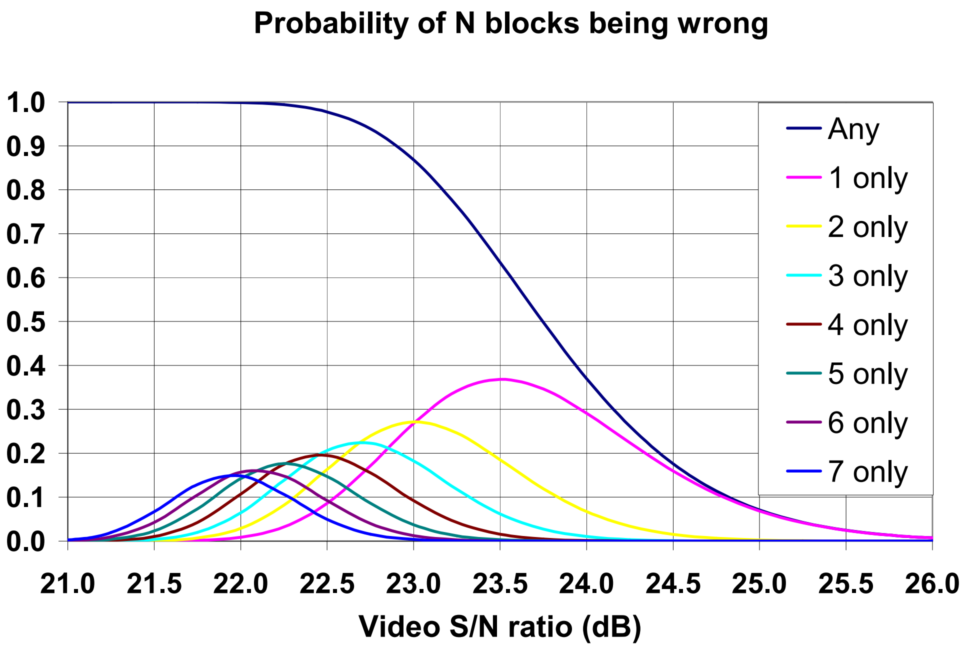

Figure F3: Probability of N blocks being wrong

This shows, for example at a video S/N ratio of 22 .5 dB, it would be very hard to predict precisely how many blocks could be wrong, although the probability of any being wrong is very high. It is useful to take the maximum point for each probability distribution and plot these in order to determine a clearer trend. However, this could be misleading as closer inspection of Figure F3 shows that the maximum probability for 2 blocks being wrong (at a video S/N ratio of 23 dB) is almost identical to the probability of 1 block being wrong. A similar pattern is followed for higher number of blocks. Therefore, two trend lines are plotted in Figure F4 to indicate this uncertainty.

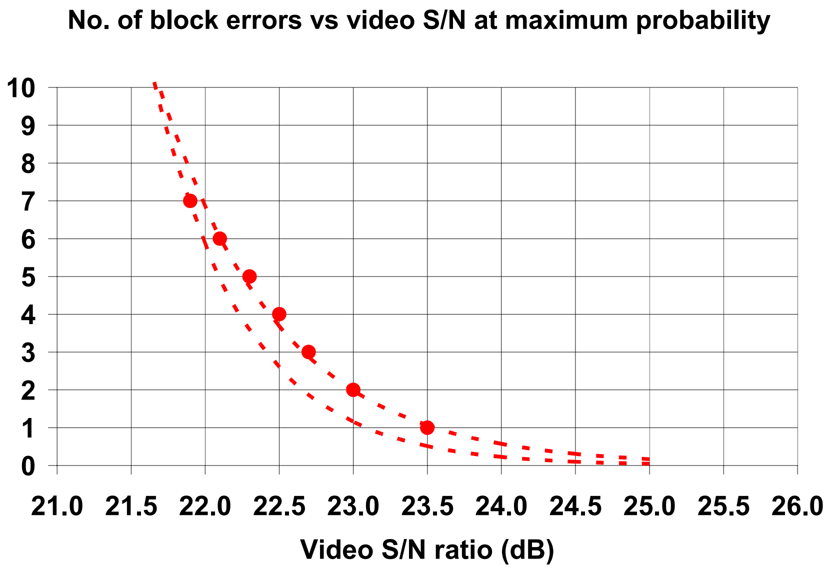

Figure F4: Maximum probability of N blocks being wrong

Although we cannot predict how many blocks will actually be wrong, what we can see is a trend of the number of blocks that are most likely to be wrong for each video S/N ratio. This is a parameter that is easy to log or record when practical tests are done.

A slightly different approach is to see if there is any significant difference between the probabilities of one or more (any) being wrong and those of that of two or more, three or more, four or more, etc. being wrong, as this may offer some degree of flexibility to the final test.

For example, the probability that four or more blocks are wrong is the probability of any block being wrong, less the probabilities that only 1 block, 2 blocks and 3 blocks will be wrong:

$$1 - (1 - P_d)^{460} - P_{1b} - P_{2b} - P_{3b}$$

This probability and a number of other examples where N blocks or more are wrong have been evaluated and are shown below in Figure F5.

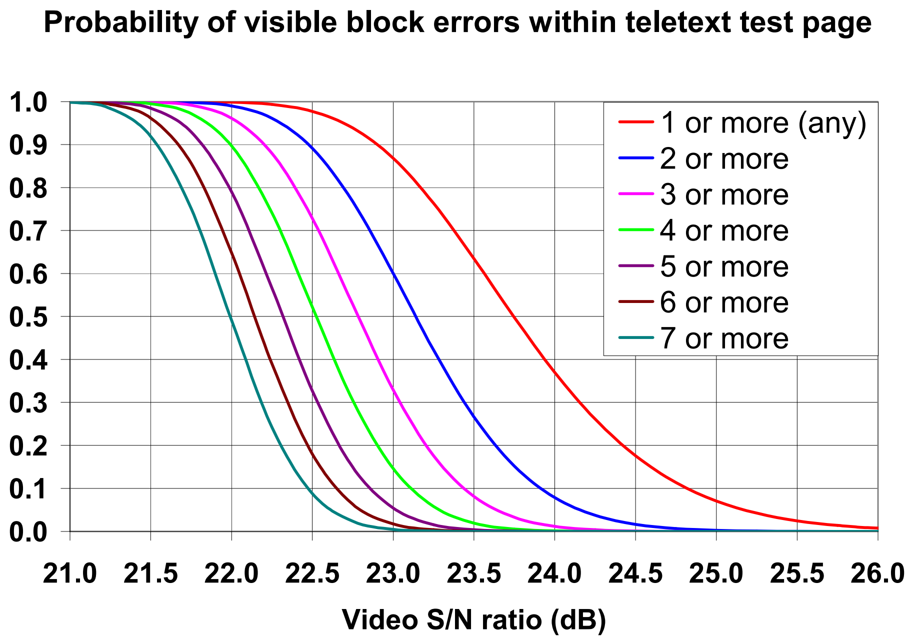

Figure F5: Probability that N or more blocks are wrong

This approach does seem to indicate that there may be a slight degree of flexibility to the final test. Also, the instructions for the final test can be simple and unambiguous; for example, “look for four or more missing blocks” or “look for any missing blocks”.

21.6 Probabilities for spaces within the whole test page being wrong

Similar calculations to that for 460 blocks can apply to 460 spaces. The probability of all 460 spaces being right is: $(1 - P_c)^{460}$ and the probability of any being wrong is: $1 - (1 - P_c)^{460}$. There is no need to consider two or more, three or more, four or more spaces, etc. being wrong, as we know that the probability of a space being wrong (P_c) is very small. For the video S/N ratios being considered, the probability of any of the 460 spaces being wrong is very close to zero and always less than the probability that blocks will be wrong. Besides, the test is based upon ‘missing’ blocks, so spaces being wrong are irrelevant.

21.7 Evaluating probabilities

Teletext data is transmitted on unused lines in the field-blanking interval. Permitted lines are 6 to 22 inclusive and 318 to 335 inclusive. A two level non-return-to-zero (NRZ) system is used. The data 0 value is black level ±2% and data 1 value is 66±6% of peak white. For a standard 1 V p-p composite video signal the transition from black to white level is 0.7 V. Thus the nominal data amplitude which we will call (A) is 462 mV. Noise will alter the data 0 and 1 values. The threshold or decision level is half the data amplitude ($A/2$). If noise alters a data 0 value above this level, or a data 1 value below this level, then a bit error will occur.

Noise is a random variant with a normal distribution and the standard deviation (σ) is equal to its RMS level. In order to find the probability that a value of ($A/2$) will be exceeded[25] and a bit error occurs, we use the complimentary cumulative distribution function. This function can be expressed in terms of the error function (*erf*). The 'end-tail' probabilities for a normal distribution can then be readily calculated.

The probability of a bit error *p* is:

$$p = \frac{1}{2}\left(1 - erf\,\frac{A}{2\sigma\sqrt{2}}\right)$$

Where A is the data amplitude and σ the RMS noise level.
For a 1 Vp-p composite video waveform the RMS noise level, is obtained from:

$$\text{Video S/N ratio (dB)} = 20\ \text{Log}_{10}(\text{RMS noise}/0.7)$$

Once the bit error probability is found, expressions above can be evaluated using the probabilities P_d and P_c previously derived and given in equations (4) and (5) above. For completeness the preceding sections have not been simplified too much or invoked any approximations. If a normal spreadsheet is used to compute overall probabilities then computational limits may result in impossible probabilities which are fractionally outside the positive number range of exactly 1 to 0. e.g. -1×10^{-99}.

It may be useful to consider the binomial theorem:

$$(a+x)^n = a^n + {}^nC_1 a^{(n-1)}x + {}^nC_2 a^{(n-2)}x^2 + \ldots + {}^nC_r a^{(n-r)}x^r + \ldots + x^n$$

Where: r is the number of binomial factors.
Expressions such as $(1 - P_d)^{460}$ where P_d is small can be evaluated with reasonable accuracy using only a small number of binomial factors.

[25] This is the probability that a data 0 will exceed a value of A/2. Alternatively (and equal) is the probability that a data 1 will be less than a value of A/2.

22 Appendix G: DigitalUK – Whitehaven leaflet

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