DVB-T transmissions
– interference with adjacent-channel PAL services

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In the UK, many of the new digital television (DVB-T) services are broadcast in adjacent channels to existing PAL services. There have been reports of PAL reception suffering as a result, possibly because the maximum DVB-T sideband levels have been incorrectly specified.

This article describes how to calculate the PAL picture impairment arising from the presence of DVB-T sidebands. It also compares the calculated predictions with experimental data. The conclusion is that the sideband specification is correct: critical viewers would just notice worst-case interference.

However, it is possible to misinterpret the specification. An allowance must be made for the difference in effective radiated powers between the DVB-T and PAL transmissions. An example is given of how a mistake could be made.

Introduction

There have been reports that some of the new digital television transmissions have been causing interference to existing PAL services in adjacent channels. Such interference could result from three possible mechanisms:

- inadequate adjacent-channel selectivity of the PAL television receivers;
- overloading of the receivers caused by the additional signals;
- generation of spurious sidebands within the DVB-T transmitters themselves.

Work has already been carried out on the adjacent-channel performance of domestic PAL receivers: BBC R&D, for example, has carried out practical tests on receivers which were reported in an internal technical note (these tests are referred to at several points in this article). If the interfering DVB-T signal is "clean" or "ideal", interference only becomes visible when its level exceeds that of the PAL signal. Since the notional transmitted power of DVB-T is typically 20 dB below that of PAL, receiver selectivity would seem adequate to avoid widespread problems.

The performance to be achieved by "real" DVB-T transmitters is specified in Chapter 11 of the "D Book" [1]. The appropriate spectrum mask, shown in Figure 11-4 of that document, was "borrowed" directly from the original ETSI specification of the DVB-T system [2]; no work was carried out within the DTG — the authors of the "D Book" — to verify the mask. The question

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now arises as to whether the mask adequately protects adjacent-channel PAL services. If the mask is "wrong", DVB-T adjacent-channel emissions could cause interference, even though the transmitters are within specification.

To answer the question, a spreadsheet has been developed which allows the transmitter spectrum mask and the receiver selectivity characteristics to be entered. From this information, the spreadsheet calculates the video signal-to-noise ratio at the output of the receiver, and hence gives a measure of the subjective picture quality. The relationship between signal-to-noise and picture quality is based on a CCIR recommendation [3], as this is the generally accepted standard. However, further work has been carried out within BBC R&D — see [4] for instance — and mention of this will be made where appropriate.

Although the spreadsheet was designed for a specific purpose, it could be used more generally for analyzing adjacent-channel performance. The spreadsheet is therefore described in some detail.

The approach

This article starts with a description of the spreadsheet design. Although reference is made to "the spreadsheet", two spreadsheets were actually developed: one for the case where the DVB-T transmission is in the *upper* adjacent channel to the PAL, the other for the case where it is in the *lower* adjacent channel. The two spreadsheets are very similar, but not identical.

It is assumed that the PAL and DVB-T transmitters are radiating with the same effective power [1], because the basic spectrum mask given in [1] makes the same assumption. However, the mask also specifies a scaling factor to be included where the powers are different. For example, if the PAL signal is really 20 dB greater than the DVB-T signal, the DVB-T adjacent-channel sidebands are also allowed to be 20 dB greater [2].

After giving a description of the spreadsheet design, the article puts the spreadsheet to use by establishing the subjective picture quality for the following cases:

- DVB-T in the *upper* adjacent channel, receiver with "*ideal*" filtering;
- DVB-T in the *upper* adjacent channel, receiver with "*real*" filtering;
- DVB-T in the *lower* adjacent channel, receiver with "*ideal*" filtering;
- DVB-T in the *lower* adjacent channel, receiver with "*real*" filtering.

In all cases, the DVB-T emissions are the maximum allowed by the mask. By using both "real" and "ideal" filtering, it is possible to distinguish between the loss of picture quality resulting from the transmitted emissions, and that caused by insufficient receiver selectivity.

1. Or rather that the two signals are being *received* at the same level. Note that the PAL transmission is characterized by its vision peak sync power, whereas the DVB-T transmission is characterized by the total power of the ensemble.
2. In practice, where the relative power of the PAL signal is as large as this, the DVB-T sideband levels are limited by the need to keep the effective noise degradation (END) of the transmitter within 0.5 dB: high sideband levels in the adjacent channel imply a high equivalent noise floor (ENF) within the "wanted" COFDM ensemble. Ref. [1] provides the relationship between ENF and END.

There follows a discussion about whether the mask is appropriate, and whether the PAL receiver performance is adequate. As mentioned in the *Introduction*, practical measurements have been made to establish typical receiver performance, and it is interesting to compare these with the predictions of the spreadsheet.

Finally, the article illustrates how problems can arise if the spectrum mask is misinterpreted.

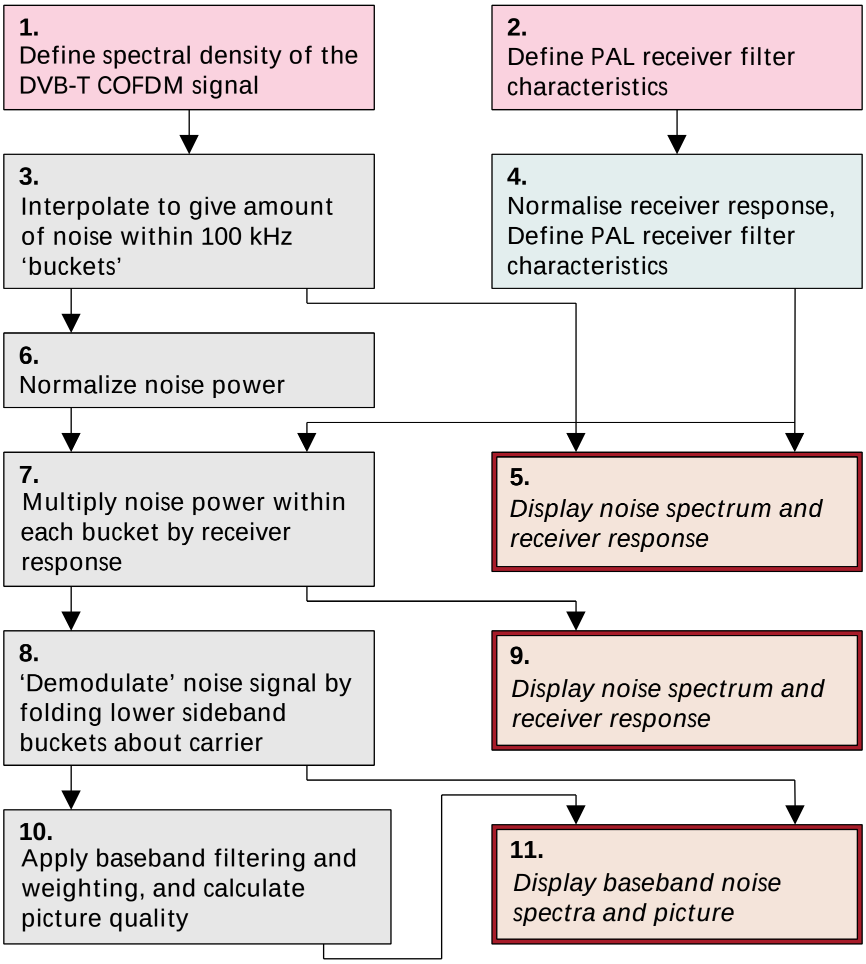

Figure 1
Flow diagram to illustrate the operation of the spreadsheet.

The spreadsheet design

The design of the spreadsheet is illustrated in *Fig. 1*. The numbering of each step corresponds to that of the following description.

1.) The DVB-T spectral density is entered in the form shown below (*Table 1*). The figures in the brown bold typeface can be altered at will. Because what is entered is the noise *power*, it is also necessary to specify the bandwidth within which that power is measured. Note that – 32.8 dB in 4 kHz is equivalent to 0 dB within the width of the ensemble.

2.) The PAL receiver response is entered in a similar manner (see *Table 2*). Note that the response at 0 MHz must be given; the other frequencies (in brown bold text) can be chosen at will.

Table 1
Entry of spectral density data

Assume the spectrum is as follows:					
–76.9	dB	at	**–12**	MHz	and below.
–76.9	dB	at	**–10.75**	MHz	
–76.9	dB	at	**–9.75**	MHz	
–70.9	dB	at	**–5.75**	MHz	
–59.9	dB	at	**–4.685**	MHz	
–56.9	dB	at	**–3.925**	MHz	
–32.8	dB	up to	**–3.9**	MHz	and above.
(Frequencies relative to centre of DVB-T channel)					
Measurement bandwidth			**0.004**	MHz	
Level of PAL rel. to DVB-T			**0**	dB	

Table 2
Entry of receiver response data.

PAL receiver characteristics:					
–47	dB	4.21E–03	(mag) at	**–1.5**	MHz
–30	dB	2.98E–02	(mag) at	**–1.25**	MHz
–5.5	dB	5.00E–01	(mag) at	**0**	MHz
0	dB	9.42E–01	(mag) at	**1.25**	MHz
1	dB	1.06E+00	(mag) at	**2**	MHz
1	dB	1.06E+00	(mag) at	**4**	MHz
0	dB	9.42E–01	(mag) at	**4.3**	MHz
–25	dB	5.30E–02	(mag) at	**5.5**	MHz
–25	dB	5.30E–02	(mag) at	**6.5**	MHz
–45	dB	5.30E–03	(mag) at	**8**	MHz
		(normalized)			
(Frequencies are relative to the PAL vision carrier)					

3.) The spreadsheet calculates the DVB-T noise power, in dB, that would exist in contiguous 100 kHz "buckets". It does this by interpolation of the information entered in step *1.)*.

4.) Similarly, the spreadsheet calculates the receiver gain at 100 kHz intervals. This time, the gain is expressed in *linear* terms before interpolation is carried out [3] — hence the column of green figures in *Table 2*. The response is also normalized to 0.5 at the carrier frequency (0 MHz).

5.) The DVB-T transmitter noise spectrum (or spectrum mask) and the receiver filter response are plotted on separate charts. The charts provide a useful check that the data have been entered correctly. Examples will be given in the following sections.

6.) The DVB-T noise spectrum is normalized by relating it to the vision peak sync power of the PAL signal — hence the reason for specifying the relative level of PAL in step *1.)*.

7.) The DVB-T noise power within each bucket is multiplied by the receiver filter response, to give the actual noise power presented to the receiver demodulator.

8.) The DVB-T noise is "demodulated" by folding over the lower sideband energy and adding it to the upper sideband energy. For example, the energy at 1 MHz below the vision carrier is added to that at 1 MHz above the vision carrier. There is also a factor of 8 dB that must be added to the "demodulated" noise spectrum, so that the noise is correctly referenced to the 0.7 V PAL picture amplitude. *Appendix 1* explains how this figure is derived.

3. It is often more appropriate to use linear interpolation when describing receiver filters. For instance, an ideal PAL-I Nyquist filter has a response which rises linearly from 0 at –1.25 MHz to 1 at +1.25 MHz. It is only necessary to specify the gain at two frequencies and the interpolation should be "perfect". If the response had been left in dB, more frequencies would have been necessary, and there would still be errors in the interpolation.

Abbreviations

CCIR	(ITU) International Radio Consultative Committee	**IP**	Intermodulation product
COFDM	Coded orthogonal frequency division multiplex	**ITU**	International Telecommunication Union
DTG	Digital Television Group	**PAL**	Phase alternation line
DVB	Digital Video Broadcasting	**RMS**	Root-mean-square
DVB-T	DVB - Terrestrial	**S/N**	Signal-to-noise ratio
ERP	Effective radiated power	**SAW**	Surface acoustic wave
		VSB	Vestigial sideband

9.) The noise spectra, before and after demodulation, are shown on the same chart.

10.) The spectrum of the noise at the output of the demodulator is lowpass filtered to limit its bandwidth to 5 MHz. In fact, the CCIR recommended filter has a slightly "soggy" response, which is –1 dB at 4.5 MHz and –3 dB at 5 MHz [5]; this response has been included within the spreadsheet. Also included is the CCIR "Rec 567-3" unified weighting network (see *Fig. 2*), which takes into account the lesser subjective effect of high frequency noise.

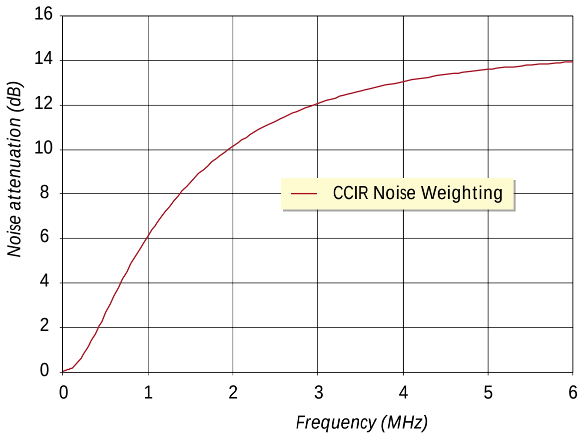

Figure 2
Response of "Rec 567-3" unified weighting network.

The weighting network obviously reduces the total amount of noise appearing at the output of the receiver. Because the picture quality is quoted by the CCIR [3] in relation to the *unweighted* noise level, the weighted noise output must be normalized. This is done by noting the attenuation suffered by white noise of 5 MHz bandwidth when passing through the filter. The attenuation factor (actually 7.5 dB) is then added to the level of the weighted noise. As a result, the apparent levels of weighted and unweighted noise will be the same when the noise spectrum is flat, but the weighted figure will be lower where high-frequency noise predominates [4].

11.) The weighted and unweighted noise spectra are plotted on a single chart, to allow easy comparison. The integrated noise power of each spectrum is also given, together with the implied CCIR picture quality grade [3] [5].

4. It might seem surprising that the CCIR weighting curve, which was originally designed for luminance signals, is appropriate for PAL-encoded video. However, Rec. 567-3 claims that the weighting curve *is* usable, provided that the noise level at 5 MHz does not exceed that at 1 MHz by more than 11 dB.

5. According to [3], the picture quality is Grade 2 at 24 dB S/N and improves approximately linearly (in terms of dB) to Grade 4.7 at 37 dB. Further details of the CCIR 5-point scale, and how the spreadsheet makes use of it, are given in *Appendix 2*.

Interference from a DVB-T transmitter in the upper adjacent channel

Fig. 3 shows the DVB-T spectrum mask for the permitted sideband levels within the *lower* adjacent channel. Note that the horizontal axis gives the frequency relative to vision carrier of the affected PAL service [6]. Increasing sideband levels are allowed above 5 MHz, and this reflects the relative robustness of the FM sound and Nicam stereo sound signals. The rising characteristic between 1 MHz and 5 MHz corresponds approximately to the CCIR weighting curve; that is, high-frequency noise is deemed less objectionable than low-frequency noise.

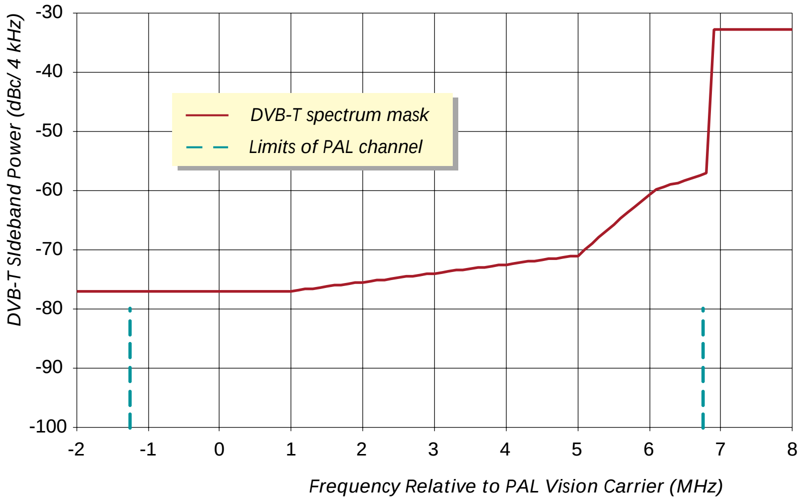

Figure 3
DVB-T lower adjacent-channel spectrum mask.

Two different PAL receiver filter characteristics have been entered into the spreadsheet. The first, shown in *Fig. 4*, is “ideal”, and has no response within the adjacent DVB-T channel. As a consequence, all interference must be the result of unwanted co-channel sidebands from the DVB-T transmitter. The filter response is assumed to fall linearly with frequency from unity at 5 MHz to zero at 5.5 MHz [7].

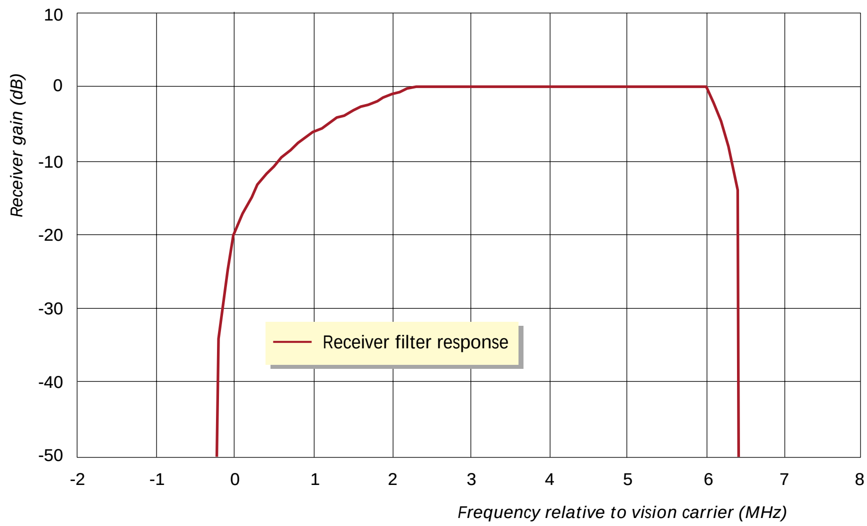

Figure 4
“Ideal” PAL receiver filter characteristics.

The second “real” filter characteristic is shown in *Fig. 5*. This is a slightly stylized representation of a typical SAW filter, designed for use in domestic television receivers. Features of interest are the “shelf” at 6 MHz, for the benefit of the sound carrier, and the ultimate out-of-band rejection of about 45 dB. The rejection at the lower boundary of the PAL channel is only about 30 dB — an important factor when the DVB-T transmission is in the lower adjacent channel, but not for the present case.

6. In the “D Book”, the spectrum mask was defined in terms of the permitted sideband energy density at a frequency relative to the centre of the DVB-T channel.
7. The exact nature of the response is not important: the CCIR low-pass filter cuts off sharply at 5 MHz.

The spreadsheet gives the results shown in *Fig. 6* for the noise appearing at the output of the “ideal” PAL receiver:

Although the unweighted video signal-to-noise ratio is only about 36 dB, high-frequency noise predominates and the picture quality is good — CCIR Grade 4.7 implies that 70% of viewers would not be aware of any degradation.

The results (see *Fig. 7)* are almost identical for the “real” receiver.

The performance is similar because, at the output of the demodulator, any DVB-T energy that has leaked through the receiver filter will be outside the 5 MHz video passband. *Fig. 8* provides an illustration; note the “breakthrough” of the DVB-T ensemble above 7 MHz:

The spreadsheet indicates that CCIR Grade 3.5 is reached at a DVB-T level of +7 dB [8]. This figure appears to agree well with the “practical” value of +3.8 dB (reported in an internal BBC R&D technical note) for a 4 dB greater sideband level. However, the agreement is largely good fortune: the characteristics of the spectra and the criteria for a Grade 3.5 picture are different in the two cases. There is a further discussion about predicted and measured results in a later section of this article.

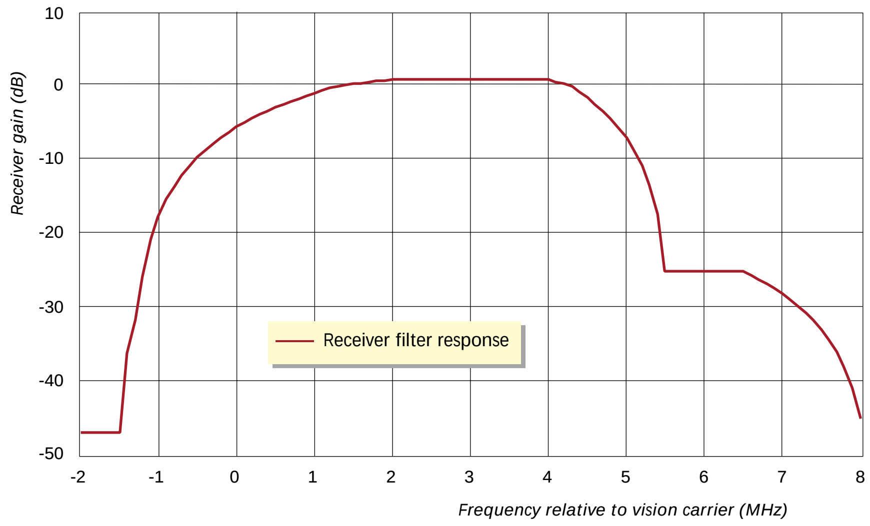

Figure 5
“Real” PAL receiver filter characteristics.

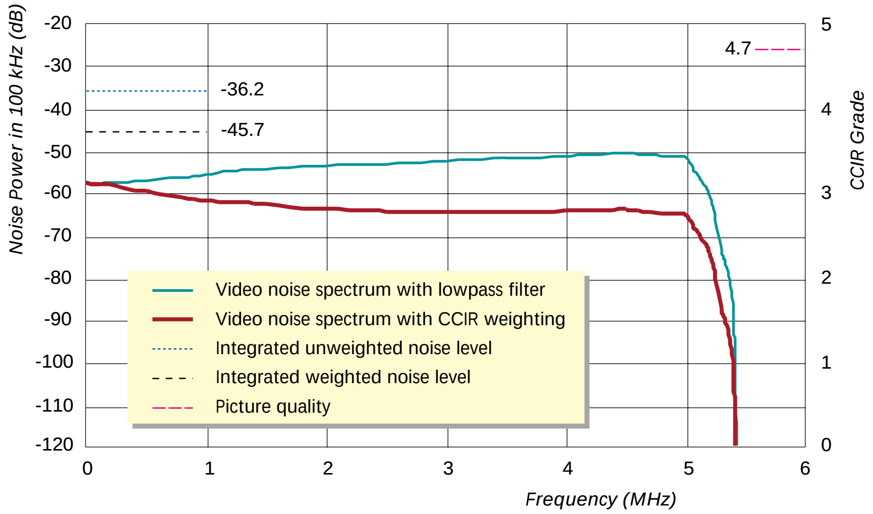

Figure 6
Noise spectra at the output of an “ideal” PAL receiver.

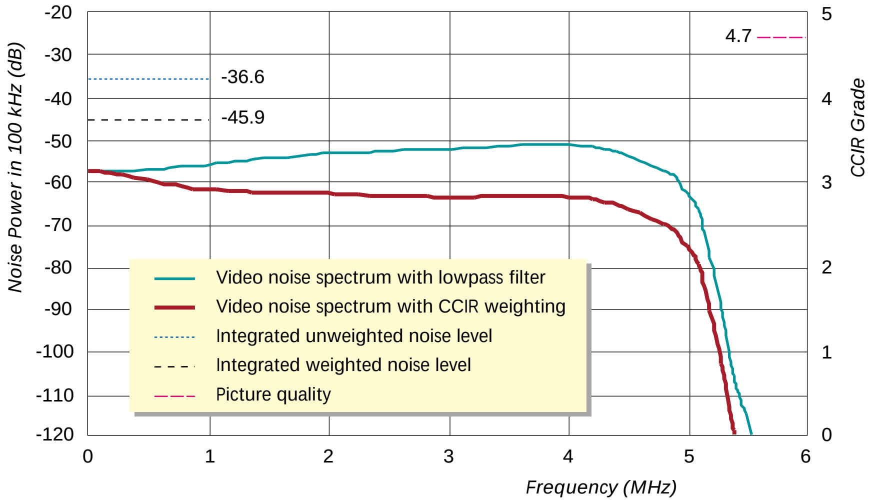

Figure 7
Noise spectra at the output of a “real” PAL receiver.

In summary, the DVB-T spectrum mask appears to impose sensible limits on emissions within the lower adjacent channel: the interference to an existing PAL service should be barely visible if the limits are observed. Within reason, receiver selectivity is not an important factor.

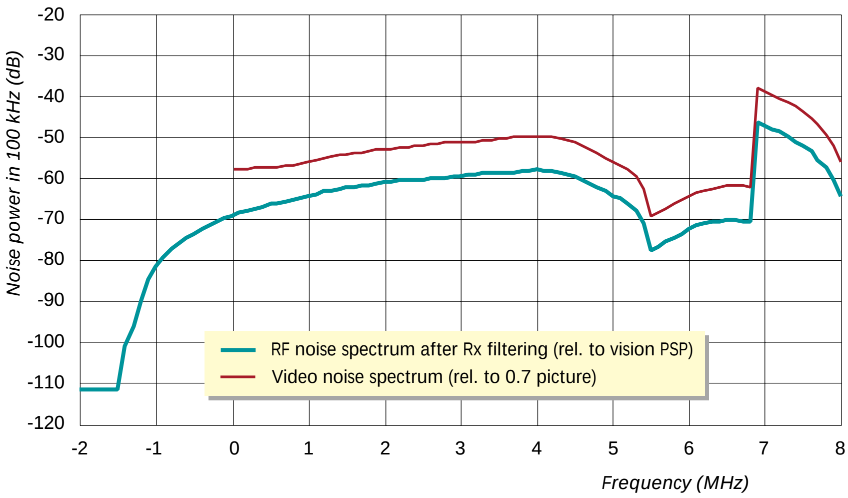

Figure 8
Noise spectra for a "Real" PAL receiver.

Interference from a DVB-T transmitter in the lower adjacent channel

Fig. 9 shows the DVB-T spectrum mask for the permitted sideband levels within the *upper* adjacent channel. Once again, the horizontal axis gives the frequency relative to the vision carrier of the affected PAL service. This time, however, there is no rising characteristic between 1 MHz and 5 MHz to correspond to the CCIR weighting curve. Presumably, the designers of the mask felt that "real" transmitters would not behave in this way. The rising characteristic from 0 MHz down to –1 MHz reflects the increasing attenuation provided by the Nyquist filter within the receiver.

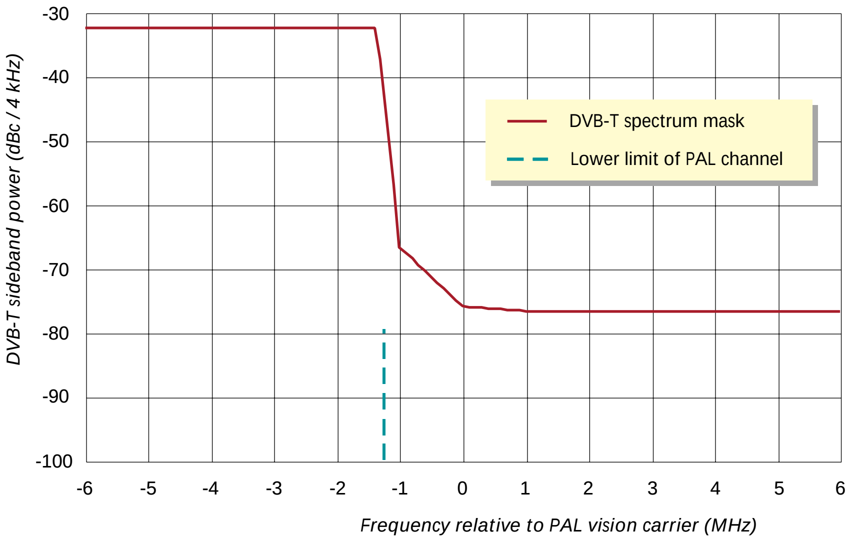

Figure 9
DVB-T upper adjacent-channel spectrum mask.

The two PAL receiver filter characteristics are exactly as they were before. This time, the performance of the "real" filter in the region of the channel boundary is very important, as will be seen. Note that the "real" response is about –6 dB (50%) at the vision carrier, as it should be, but has only fallen to –30 dB at the –1.25 MHz channel boundary.

The spreadsheet gives the results shown in *Fig. 10* for the noise appearing at the output of the "ideal" PAL receiver.

8. The sideband level relative to the DVB-T carrier power has been kept constant — not scaled as specified in [1].

The signal-to-noise ratio, at nearly 39 dB, is slightly better than before. However, the noise now has a nearly constant spectral density, and the picture quality is almost identical (CCIR Grade 4.7). An interesting feature is the small "blip" centred on 1.25 MHz, which is caused by the DVB-T sideband energy existing at this frequency *below* vision carrier. As can be seen in *Fig. 11*, the blip is more serious when the receiver filtering is "real".

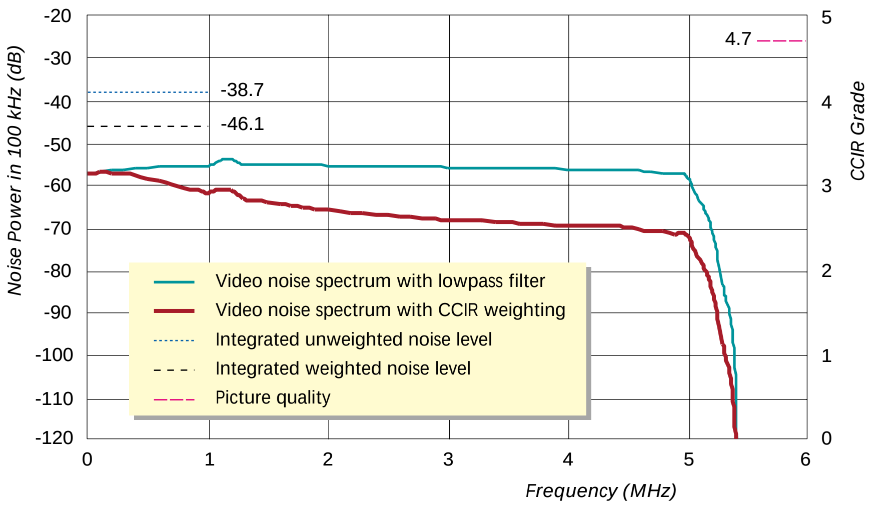

Figure 10
Noise spectra at the output of an "Ideal" PAL receiver.

Not only is the blip more pronounced, but there is also a general increase in DVB-T energy over most of the video spectrum. The additional energy is caused by some of the "wanted" DVB-T signal leaking through the receiver filter, not by spurious sidebands from the DVB-T transmitter. Spectral energy that was originally present below –1.45 MHz is "folded over" by the demodulator, so that it now appears above +1.45 MHz. There is nothing that can be done at the transmitter to improve matters. Picture quality corresponds to CCIR Grade 4.5 — slightly worse than before, but implying that the degradation would still be imperceptible to about 50% of viewers.

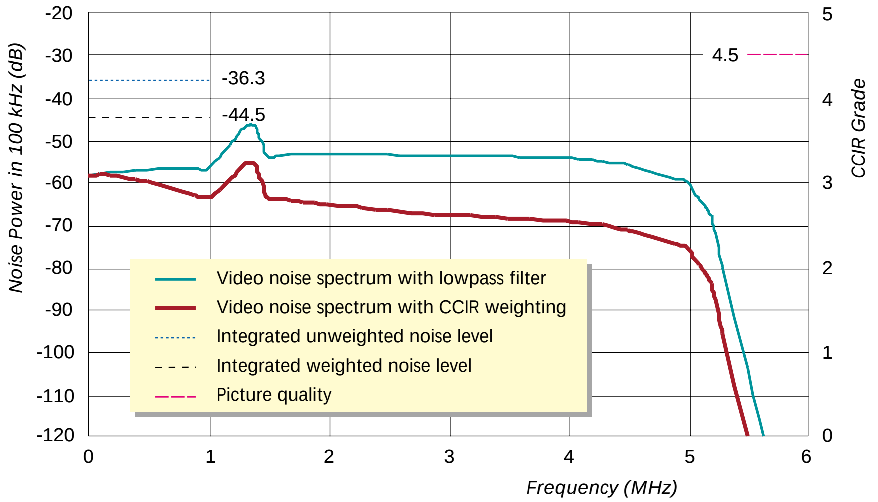

Figure 11
Noise spectra at the output of a "real" PAL receiver.

The spreadsheet indicates that CCIR Grade 3.5 is reached at a relative DVB-T level of +6 dB and +7.9 dB for "real" and "ideal" receivers respectively. Note the difference between the two figures, indicating the significant effect of the receiver filter; the difference was negligible when the DVB-T transmitter was in the upper adjacent channel. The practical figure quoted in a BBC R&D technical note is +0.1 dB. As will be seen in the next section, agreement with the spreadsheet value for the "real" receiver is reasonable, once allowance has been made for such factors as the 4 dB difference in sideband level [9].

In summary, the DVB-T spectrum mask appears to impose sensible limits on upper adjacent-channel emissions: as was true for the case of lower adjacent-channel emissions, the maxi-

9. A slight word of caution is needed. As *Fig. 11* shows, at high DVB-T signal levels the imperfect receiver filtering gives rise to a "blip" at 1.25 MHz. This blip, if pronounced, can cause greater subjective degradation to the picture than would be suggested by the total amount of noise energy: the interference is more akin to that caused by a plain carrier. However, the blip is insignificant at usual DVB-T levels.

mum interference allowed by the mask would be just visible on an otherwise unimpaired PAL picture. Note, however, that receiver selectivity becomes a significant factor where the DVB-T level exceeds that of the PAL level.

Comparison of practical and calculated results

The work described so far suggests that the DVB-T spectrum mask imposes sensible limits on upper and lower adjacent-channel emissions. In each case, the worst picture quality is CCIR Grade 4.7 — which implies that seven out of ten viewers would not notice the degradation. It is true that further degradation is possible with a high-level DVB-T transmission in the lower adjacent channel, but this is the result of imperfect filtering within the receiver; tightening the spectrum mask would not help.

The visibility of noise in a PAL television system was considered in great detail by BBC Research Department. During 1986, a series of subjective tests were performed and the results presented in a Report [4] two years later. An important conclusion was that observers had become more critical over the previous twenty years: the BBC found that about 2.5 dB less noise was required to produce a given level of impairment than the figures reported in earlier work [10,11]. The difference was attributed partly to improvements in equipment, partly to increased expectations of the viewers. With an appropriate correction, agreement between the predictions of the spreadsheet and the practical results given in a BBC R&D internal technical note is good, at least for the case of DVB-T in the lower adjacent channel (*Table 3*).

Table 3
Comparison between spreadsheet predictions and measured results.

	Relative DVB-T level for CCIR grade 3.5 (dB)			
	Upper adjacent channel DVB-T		Lower adjacent channel DVB-T	
	"Ideal" Receiver	"Real" Receiver	"Ideal" Receiver	"Real" Receiver
Spreadsheet prediction	7.0	7.0	7.9	6.0
. . . with 3 dB allowance [11]	**4.0**	**4.0**	**4.9**	**3.0**
Practical measurement [a]		(3.8)		0.1
. . . with 4.1 dB allowance		N/A		**4.2**

a. The figures given here are those quoted in an internal BBC R&D technical note for a "Pattern" picture. They represent averages over three different PAL receivers.

Table 4
Comparison between spreadsheet predictions and measured results (actual spectrum).

	Relative DVB-T level for CCIR grade 3.5 (dB)			
	Upper adjacent channel DVB-T		Lower adjacent channel DVB-T	
	"Ideal" Receiver	"Real" Receiver	"Ideal" Receiver	"Real" Receiver
Spreadsheet prediction	13.0	13.2	5.8	5.3
. . . with 3 dB allowance	**10**	**10.2**	**2.8**	**2.3**
Practical measurement [a]		**+3.2 to +6.2**		**–0.4 to +2.6**

a. This time, the range of values quoted in an internal BBC R&D technical note is given; that is, the total range for all types of picture and all models of receiver. Of course, the "average" value for "Pattern" is the same as it is in *Table 3*.

10. The difference was actually 2 dB at Grade 4.5 and 3.5 dB at Grade 3. An allowance of 3 dB has been made at Grade 3.5.

Ranulph Poole *received a degree in physics from Oxford University in 1974. In that year he joined BBC Transmitter Operations, where he was involved with the maintenance of a wide range of broadcast equipment. He moved to BBC Design and Equipment Department in 1989, to assist with the development of PAL television test equipment and the introduction of Nicam sound.*

Since 1994, Mr Poole has been working in BBC Research and Development on the performance requirements for DVB-T transmission equipment. He has been an active member of the UK Digital Television Group and the ACTS VALIDATE project.

The "4.1 dB allowance" arises from the –40 dBc sideband level of the modulator used for the practical measurements; the level allowed by the mask is –44.1 dBc. Because the sideband spectrum of the modulator does not match the characteristics of the mask, such an allowance is only an approximation. However, the approximation is reasonable when the DVB-T signal is in the lower adjacent channel, when most of the sideband energy falls close to the PAL vision carrier.

In the upper adjacent channel case, most of the unwanted energy from the "practical" modulator falls at the top end of the channel and is a poor match to the mask. The apparently good spreadsheet prediction is no more than a coincidence.

Another useful exercise is to enter into the spreadsheet (in place of the spectrum mask) details of the DVB-T spectrum used during the earlier BBC R&D practical tests. The predictions of the spreadsheet can then be compared directly with the practical results (*Table 4)*

Agreement is good for the case of DVB-T in the lower adjacent channel. As mentioned before, DVB-T levels much in excess of 0 dB are likely to cause intermodulation within the receiver; hence the poor agreement for the upper adjacent channel case is not surprising [12]. In practice, to achieve a Grade 3.5 picture degradation without overloading the receiver, the DVB-T sideband levels would need to be about 10 dB greater. Unfortunately, no such experimental figures are available.

The design of the spreadsheet was based on the assumption that unwanted DVB-T sidebands can be treated as Gaussian noise. However, the sidebands generated by a "real" DVB-T transmitter are mainly intermodulation products (IPs), not Gaussian noise, and it is important to determine whether the assumption is valid. It is true that the DVB-T COFDM ensemble has the properties of Gaussian noise, but the IPs are the result of a non-linear process and are no longer Gaussian. The peak-to-mean ratio is much larger, and their appearance on a spectrum analyzer display is more "spiky". An experiment to determine the relative subjective effects of IPs and Gaussian noise is described in *Appendix 3*. The conclusion is that the subjective impairments can be treated as equivalent.

11. Another interesting point made in [4] is that "VSB noise" is less objectionable than "flat (white) noise": about 1.3 dB more VSB noise is required for a given degradation. VSB noise results when white noise is presented to a receiver containing a Nyquist filter. In the case of PAL System I, the spectrum of the noise at the output of the demodulator is 3 dB lower at 0 MHz than it is at 1.25 MHz. Something of this effect can be seen in *Fig. 7*. In the present work, no allowance is necessary for the factor of 1.3 dB because, in effect, this has already been made by the CCIR Rec. 567 weighting.

12. The BBC R&D internal technical note also quotes results for sideband levels other than –40 dBc. These confirm that receiver performance is likely to be the dominant factor at DVB-T levels greater than about 0 dB relative to PAL, whereas sideband interference dominates below this.

An example of a practical problem

An example of how problems can arise is illustrated in *Fig. 12*. The two superimposed plots represent the field-strength measurements that might be made during a helicopter survey of a transmitting station [13]. The DVB-T antenna has been designed so that very little energy is transmitted to the south. The existing PAL services are transmitted from a different antenna. Once again this is directional, but less attempt has been made to minimize the energy radiated to the south. The maximum field strengths are shown normalized to unity, although, of course, the actual maximum values are likely to be very different.

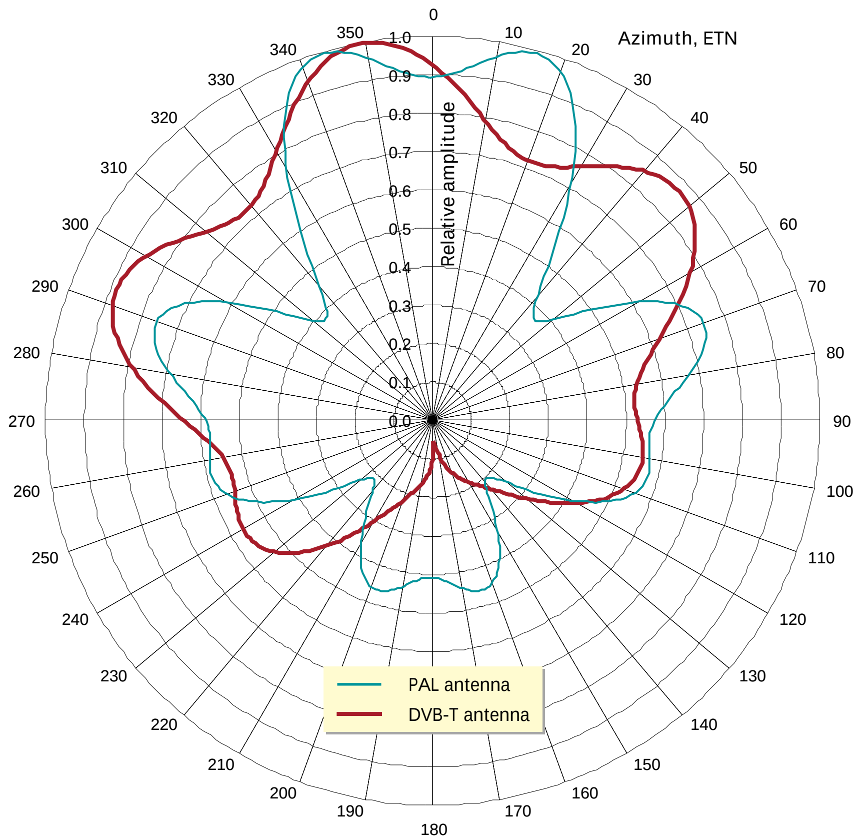

Figure 12
Horizontal radiation patterns for PAL and DVB-T antennas.

The differences between the PAL and DVB-T radiation patterns are considerable: at 15° the PAL signal is about 3 dB greater than the DVB-T signal, whereas at 45° it is some 7 dB less. At 225°, the difference is even greater, but probably there would not be many viewers on that bearing.

Suppose that the DVB-T transmission is in the lower adjacent channel to the PAL signal, and that its spectrum mask has been determined on the assumption that the two radiation patterns are identical. Suppose also that the DVB-T transmission just meets this mask. If the radiation patterns really were identical, the weighted signal-to-noise ratio at the output of an ideal PAL receiver would be 46 dB. The picture quality corresponding to this amount of noise is Grade 4.7. At 45°, however, the signal-to-noise ratio is actually 7 dB less, and the picture quality has fallen to Grade 3.5.

The same arguments can be applied to a DVB-T transmission in the upper adjacent channel. At 45°, this could add a similar quantity of noise to the output of the PAL receiver. If both upper and lower adjacent-channel transmissions were present simultaneously, the resulting weighted signal-to-noise ratio would be 36 dB, corresponding to Grade 3 picture quality. Actual viewers could be even worse off as a result of local reception conditions.

The above discussion makes clear the need to take due notice of the "D Book" stipulation: "*The following proportional correction may be added [to the spectrum mask] if the radiated powers from the two transmitters are not identical:* **correction = minimum analogue ERP (dB) – maximum dig-**

13. The measurements illustrated are fictitious. However, they are close to those obtained from a "real" survey.

ital ERP (dB)". In practice, the amounts of noise contributed by the DVB-T transmitters should not be as great as suggested above. If, for example, the lower adjacent-channel DVB-T transmitter has a maximum effective radiated power of –17 dB relative to the PAL ERP, the unwanted sideband energy may be 17 dB greater than the values given in the mask – a sideband level of –27 dBc [14]. The DVB-T signal would suffer an equivalent noise degradation (END) of about 1 dB. This is unacceptably high: a "compliant" transmission [1] has an END within 0.5 dB, which implies a sideband level below –30 dBc. The corresponding PAL picture quality is Grade 4.2.

Conclusions

This article has described a spreadsheet to evaluate the degradation of PAL picture quality, resulting from the presence of an adjacent-channel DVB-T transmission. It has been assumed that the DVB-T interference takes the form of Gaussian noise. Although actual COFDM intermodulation products (IPs) are not Gaussian, the evidence is that equal quantities of IPs and Gaussian noise give rise to equal losses of picture quality.

The spreadsheet has been put to use to demonstrate that the DVB-T spectrum mask given in the "D Book" is satisfactory. If the CCIR relationship between PAL picture quality and signal-to-noise ratio is taken, a DVB-T transmitter in either the upper or the lower adjacent channel could degrade a previously "perfect" picture to Grade 4.7. More recent work carried out at the BBC Research Department has indicated that modern viewers are more critical than those who took part in the work quoted by the CCIR. The difference amounts to about 2 dB for relatively unimpaired pictures, so Grade 4.7 is reduced to Grade 4.5. Even so, Grade 4.5 probably represents a sensible limit.

Agreement between the predictions of the spreadsheet and the results of recent subjective measurements is generally good. However, it must be remembered that "real" PAL television receivers are likely to be overloaded if the power of the DVB-T signal exceeds the PAL peak sync power. The spreadsheet takes no account of such non-linear effects. Generally this is not a serious shortcoming, as the DVB-T transmissions are typically 20 dB below the PAL signal.

An example of a possible problem has been given. PAL and DVB-T signals are always transmitted from the same site, but not necessarily the same antenna. Radiation patterns can therefore vary considerably, and some receiving locations will receive high relative levels of DVB-T. Consequently, the DVB-T spectrum mask should be scaled to suit the most unfavourable locations. A statement to this effect already accompanies the mask.

Bibliography

[1] **Digital Terrestrial Television: Requirements for interoperability — The "D Book", Version 3.0.**
Digital Terrestrial Group (DTG), 1998.

[2] ETS 300 744: **Digital broadcasting systems for television, sound and data services: Framing structure, channel coding and modulation for digital terrestrial television**
ETSI, 1996.

14. "dBc" means "dB relative to the carrier power of the wanted DVB-T signal".

[3] CCIR Recommendation 654 (i.e. ITU-R Rec. BT.654): **Subjective quality of television pictures in relation to the main impairments of the analogue composite television signal**
ITU, Geneva, 1986.

[4] A. Oliphant et al.: **The visibility of noise in System I colour television**
BBC R & D Report 1988/12.

[5] CCIR Recommendation 567-3: **Unified weighting network for random noise**
ITU, Geneva, 1986

[6] CCIR Recommendation 500 (i.e. ITU-R Rec. BT.500-9): **Methodology for the subjective assessment of the quality of television pictures**
ITU, Geneva, 1999.

Appendix 1: Relationship between signal-to-noise ratios before and after demodulation

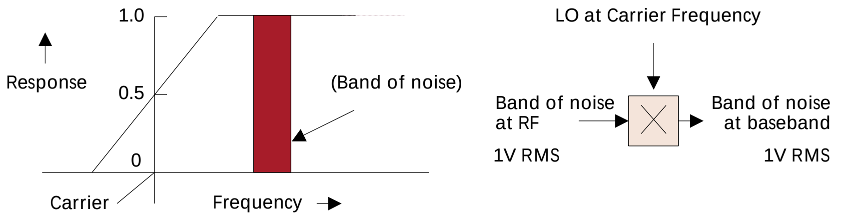

Figure A1.1
Illustration of Nyquist filter and synchronous demodulator.

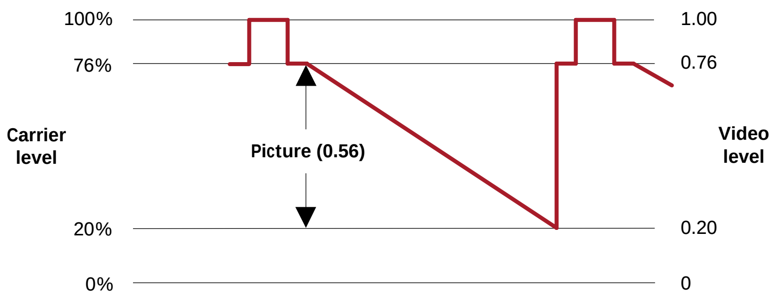

Figure A1.2
Illustration of PAL System I signal before and after demodulation.

It was stated earlier (in the section titled *The spreadsheet design)* that the signal-to-noise ratio of a PAL System I signal is worsened by 8 dB as a result of the demodulation process. As this figure might appear surprising, a short explanation is given here.

Assume the receiver (see *Fig. A1.1)* possesses a standard Nyquist shaping filter, followed by a synchronous demodulator with unity gain.

If a band of noise of level 1 V RMS is presented to the receiver, 1 V RMS will appear at the output, provided that the filter has a response of unity. The same would be true if the noise were replaced with a sinusoidal signal. If a 1 V RMS vision carrier is now applied in place of the noise, the signal level reaching the demodulator is 0.5 V RMS, because of the response of the Nyquist filter. The demodulator output is now a DC voltage corresponding to the *peak* vision carrier level, or $0.5 \times \sqrt{2}$ V [15].

The demodulated noise level is normally referenced to the video picture amplitude, not the peak sync level.

The DC emerging from the demodulator has already been calculated as $0.5 \times \sqrt{2}$ V, for 1 V RMS vision carrier at the input of the receiver. If this 1 V RMS represents the vision peak sync level, it follows that the picture amplitude will be $(0.5 \times \sqrt{2}) \times 0.56$ V at the demodulator output. Thus, whereas 1 V RMS noise at the receiver input results in 1 V RMS noise at the output, 1 V RMS peak sync PAL results in only $(0.5 \times \sqrt{2}) \times 0.56$ V picture. The ratio of the picture level to noise level amounts to – 8.047 dB.

Appendix 2: The CCIR 5-point impairment scale

The principles to be adopted for the assessment of subjective picture quality are set out in CCIR Recommendation 500 [6]. Observers are asked to grade the test picture by using the CCIR 5-point impairment scale (see *Table A2.1)*.

Table A2.1
CCIR 5-point impairment scale.

Grade (Q)	Impairment	Picture Quality
5	Imperceptible	Excellent
4	Perceptible, but not annoying	Good
3	Slightly annoying	Fair
2	Annoying	Poor
1	Very annoying	Bad

Quite often, an impairment is described by a fractional grade, for instance Grade 4.7. This is because the grade is calculated by averaging the opinions of a large number of observers: Grade 4.7 implies that 70% of the observers described the picture as Grade 5, and 30% as Grade 4. CCIR Recommendation 654 [3] gives the relationship between unweighted video signal-to-noise ratio and picture quality: 29 dB corresponds to Grade 3, and adjacent grades are separated by about 4.5 dB. (There is a larger gap between Grades 4 and 5.)

The spreadsheet described in this article calculates the *weighted* S / N. According to CCIR Recommendation 567 [5], the weighted S / N is 7 – 4 dB greater than the unweighted S / N (i.e. S/N_{UW}). Hence the algorithm used in the spreadsheet to relate weighted S / N (S/N_W) to the grade is as follows:

$$Q = 2 + \{((S/N_W - 7.4) - 24) / 4.7\} - \{((S/N_W - 7.4) - 24)^3 / 8{,}000\}.$$

This formula gives Q = 2 when:

$$S/N_{UW}\ (= S/N_W - 7.4) = 24$$

15. This assumes, of course, that the demodulator is correctly “phased up”. If the local oscillator has a phase error of 90°, for instance, there will be no output from the demodulator!

Initially, Q increases by 1 for a 4.7 dB increase in S/N, but above Q = 4, the cubic term slows the rate of increase. Q remains at 5 for all S/N_W greater than 48 dB, as illustarted in *Fig. A2.1*.

The data points taken from CCIR Rec. 654 are also shown. These were estimated from a graph, and therefore do not fall exactly on the line.

Later work carried out by BBC Research Department [4] suggests that the CCIR Recommendation is optimistic, and that modern viewers would require the S/N to be improved by about 2.5 dB for a given picture degradation.

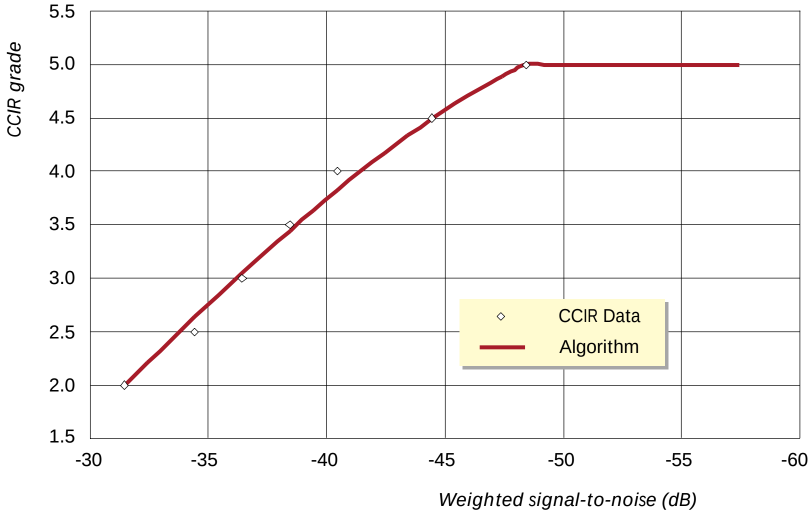

Figure A2.1
Relationship between picture quality and weighted signal-to-noise ratio.

Appendix 3: The relative visibility of Gaussian noise and DVB-T intermodulation products

When considering the question of co-channel DVB-T interference to PAL transmissions, it is often convenient to assume that the DVB-T signal has the same properties as a filtered band of Gaussian noise. Whilst this assumption is reasonable, it does not follow that any intermodulation products (IPs) falling within the adjacent channel are also similar to Gaussian noise. Since the IPs are generated by non-linearity, one would expect the quasi-peak-to-mean ratios to differ: the IPs have the higher peak-to-mean ratio and are therefore more “spiky”; they do not obey Gaussian statistics. The difference in nature is easily seen on a spectrum analyzer display.

As the IPs of the DVB-T signal are non-Gaussian, the subjective effect on a PAL picture could differ from that of Gaussian noise. Perhaps one might expect that the spiky nature of the IPs would make them more visible. In order to determine the relative subjective effects, the equipment shown in *Fig. A3.1* was set up.

A broadband noise source is split into two alternative paths, which are individually processed before being added as interference to the PAL signal. The first path contains no more than an attenuator, and provides a reference quantity of Gaussian noise. The second path is more complicated. A bandpass filter selects a 25 MHz-wide band of noise, so creating what amounts to a dummy DVB-T COFDM ensemble. The noise is then passed through an amplifier at such a level that third-order IPs are generated at approximately –25 dBc. A second filter removes the original “wanted” dummy ensemble, leaving a band of IPs centred on the PAL channel and about 10 MHz wide. A switch allows a rapid changeover between the two types of noise. Because the spectrum of the IPs is not quite flat, the second filter is tuned so as to provide equalization.

The PAL signal is provided by a video testcard generator and PAL modulator. It is viewed on a good-quality domestic television receiver with carefully adjusted brightness and contrast controls. A Tektronix VM700 video analyzer is connected to the video output of the receiver, so as to enable accurate measurement of the picture signal-to-noise ratio. The testcard chosen is that referred to as “Pattern” in the BBC R&D internal technical note (frequently referred to throughout this article), and deemed to be “critical” material; that is, it tends to reveal any interference that is present.

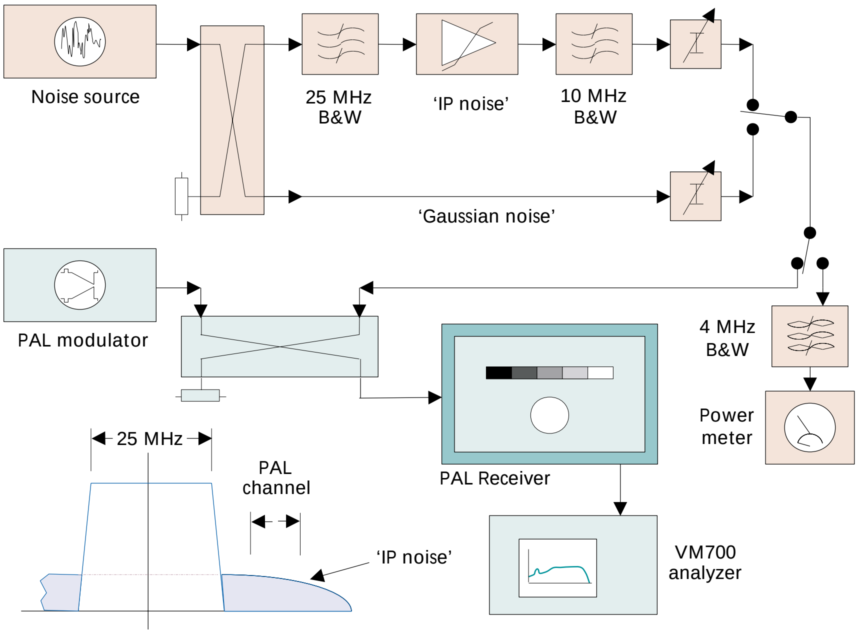

Figure A3.1
Simplified block diagram of the test arrangement.

Details of the test method are generally similar to that described in the BBC R&D internal technical note. “Gaussian noise” was selected, and its level adjusted for the required video signal-to-noise (S/N) as indicated on the VM700; for example, 32.5 dB signal-to-”VSB noise” would correspond to CCIR Grade 3.5. The switch was then set to “IP noise”, the IP noise level adjusted until the subjective picture quality was the same as before, and the noise level measured. A combination of a 4 MHz wide bandpass filter centred on the PAL channel and a true power meter allowed accurate measurements of relative noise powers. The measurements were repeated a number of times, so as to obtain a useful average.

Table A3.1
Levels of IP noise relative to Gaussian noise for equal subjective effect.

CCIR Grade *and S/N (dB)*	Rel. level (dB) Observer 1	Rel. level (dB) Observer 2	Average and *Standard Dev’n (dB)*
	+0.1	–0.7	
3.5	–0.6	0.0	**–0.19**
	–0.4	+0.6	
32.5	–1.0	–0.1	***0.46***
	–0.1	+0.3	
	–1.3	–0.3	
3.0	–0.2	+0.2	**–0.33**
	+0.1	–0.4	
31.0	0.0	+0.4	***0.42***
	–0.2	+0.8	

The results are shown in *Table A3.1*.

The two types of noise could be easily distinguished on the picture: the large peak-to-mean ratio of the IP noise gave rise to “sparklies” — particularly visible in dark areas. Despite this, the measured power levels for equal subjective effect were nearly the same — a surprising result. Combining the results for Grades 3 and 3.5 shows that the IP noise is more objectionable by about 0.25 dB, and that the standard deviation of the results is about 0.3 dB.

Clearly, there is further work to carry out on this subject: the measurements given above amount to little more than a “look-see” exercise. Nevertheless, it appears that, for equal power levels, IP noise is not appreciably more objectionable than Gaussian noise. When designing spectrum masks, there is therefore no need to make an allowance for the difference.

Acknowledgements

Thanks are due to John Salter (BBC R&D) for providing the experimental data quoted in this report. Both John and Chris Nokes (also BBC R&D) offered helpful advice and suggested corrections.