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Digital Television services:
The revised spectral mask for PAL-I transmitters and its effect on PAL-I reception

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Digital Television services: the revised spectral mask for PAL-I transmitters and its effect on PAL-I reception

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Abstract

The introduction of Digital Terrestrial Television (DTT) in the UK will require the use of UHF channels adjacent to those occupied by existing PAL-I services. There are potential engineering problems resulting from this, one of the most serious of which is posed by the high level of PAL-I sidebands radiated within the lower adjacent channel.

Work carried out at BBC Research and Development has shown that such interference can be avoided by ensuring the PAL transmission conforms to a modified System B/G spectral mask. (In effect, the new mask reduces the width of the vestige from 1.25 MHz to 0.75 MHz.) However, PAL-I receivers are designed to make full use of the 1.25 MHz vestige, and modification of the mask must lead to some distortion of the demodulated signal. The extent of the distortion is evaluated in this Paper.

The conclusion is that the errors present at the output of a high quality ‘professional’ receiver are small. They are negligible for a domestic set.

This Paper was originally written in 1997, and circulated amongst groups interested in the subject.

Key words: digital television, transmission, reception, spectral mask, PAL-I, DTT

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Authorisation of the Head of Research is required for publication.

1. Introduction

To allow Digital Terrestrial Television (DTT) to be implemented, service planning considerations dictate that about half the transmissions need to be placed adjacent to existing analogue (PAL-I) services. These adjacent channel DTT transmissions divide approximately equally between upper and lower adjacent channels. In the past, these portions of the terrestrial UHF spectrum have been considered 'taboo' because of the engineering difficulties involved in making use of them. Of course, this is one of the reasons that they are now available for the digital transmissions.

One of the most serious problems is the high level of PAL-I sidebands presently radiated within the *lower* adjacent channel. These sidebands will cause interference to any digital service occupying that channel — a situation made worse by the relatively low level of the digital signal. Earlier work has shown that interference can be avoided by adoption of a modified System B/G spectrum mask. In essence, the new mask requires the width of the vestige to be reduced from 1.25 MHz to 0.75 MHz, with a high rate of sideband attenuation outside the vestige.

However, PAL-I receivers are designed to make full use of the 1.25 MHz vestige, and so any reduction of the vestige width will lead to distortion of the demodulated signal. The work carried out to assess the extent of the distortion is described in the present Paper.

2. This Document and the Scope of the Work

This report starts with a simple discussion of the distortions to be expected at the output of an 'ideal' PAL-I receiver as a consequence of reducing the width of the transmitted vestige. A simulation was carried out to quantify the distortions, and the results of this are presented. There follows a description of the test set-up used to measure the distortions appearing at the outputs of 'real' receivers. A particular feature of the set-up was the ability to alter the apparent width of the vestige conveniently. Two different vestigial sideband (VSB) filters were available:

- A modern 'professional' SAW filter with a sharp cut-off.
- A filter comprising discrete inductors and capacitors. This was an integral part of the Rohde and Schwarz PAL-I test modulator. Although it had a slower cut-off than the SAW filter, its performance still met the PAL-I specification.

The report continues by presenting the results of the measurements made on the following:

- Subjective picture quality.
- 2T pulse and bar.
- Ceefax eyeheight.

For the sake of completeness, four different receivers were used:

- A high quality 'professional' receiver, such as could be used for quality monitoring or rebroadcast links.
- A 'top-of-the-range' domestic receiver, employing SAW IF filtering.
- A 'budget quality' domestic receiver, again using SAW IF filtering.
- An elderly domestic-style receiver, using discrete inductors and capacitors for the IF filtering.

Finally, the conclusion reached is that the signal distortions resulting from the reduction in vestige are insignificant, even when measured at the output of a 'professional' receiver.

3. The Effects of Reducing the PAL-I Vestige

The diagram below illustrates the spectrum of an existing PAL-I transmission in relation to that of a lower adjacent channel DTT signal. Two possible sources of PAL-I interference to the DTT signals are apparent.

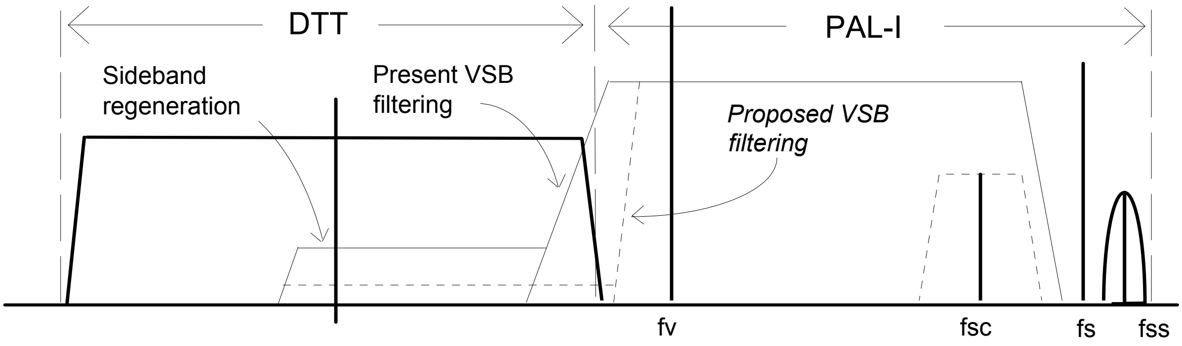

Figure 1: Typical Adjacent Channel PAL-I and DTT Spectra

Close to the boundary between the two channels, sideband interference is mainly a consequence of the slow roll-off of the VSB filter: the current specification does not require more than 8 dB attenuation at 2 MHz below vision carrier — 0.5 MHz within the DTT ensemble. Further from the boundary, interference is dominated by sidebands regenerated within the final amplifier of the transmitter. These sidebands are the consequence of non-linearity, and are images of the wanted upper sidebands about the vision carrier.

To avoid the likelihood of PAL-I interference to DTT transmissions, the proposal is to use a System B/G VSB filter which provides at least 30 dB of sideband attenuation at 1.4 MHz below the vision carrier. It is also necessary to reduce the image sidebands resulting from transmitter non-linearity, and the method is to fit a high-order bandpass filter at the transmitter output. Typically, the overall sideband response will be −2 dB at (fv − 0.75) MHz and −20 dB at (fv − 1.25) MHz, where fv is the frequency of the vision carrier.

Unfortunately, PAL-I receivers are equipped with Nyquist filters designed to make full use of the 1.25 MHz vestige, and distortion will result if the vestige is reduced. The diagram below illustrates why this is so:

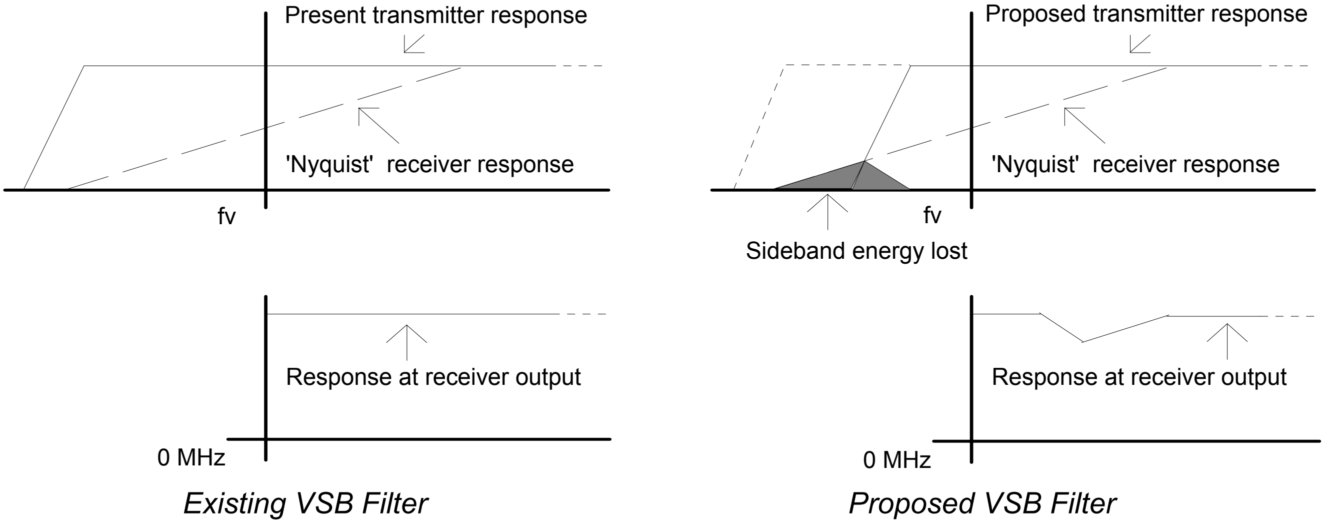

Figure 2: The Effect of Reducing the Transmitted Vestige

The demodulated signal at the output of the receiver is made up of the sum of the upper and lower sidebands; the Nyquist filter, by virtue of its symmetry about vision carrier, ensures that this sum is unity for all video frequencies[1]. If the transmitted vestige is now reduced, the lower sidebands cannot make their full contribution to the output of the receiver, and the result is a 'dip' in the frequency response. The depth of the dip is simply calculated, as shown in the example below:

Existing PAL-I VSB filtering

Contribution of upper sideband at fv + 0.75 MHz is (0.75 + 1.25) / 2.5	= 0.8
Contribution of lower sideband at fv – 0.75 MHz is (–0.75 + 1.25) / 2.5	= 0.2
Sum of the two contributions	= 1.0

Proposed PAL-I VSB filtering

Contribution of upper sideband at fv + 0.75 MHz is as above	= 0.8
Contribution of lower sideband at fv – 0.75 MHz is halved (say)	= 0.1
Sum of the two contributions	= 0.9

In this case the response error is $20 \log_{10} 0.9$ dB, which equals about −1 dB.

Although the response error appears to be serious, the practical effect is not necessarily large: most 'real' video waveforms result in sideband energy being spread over a frequency range which is wide compared with the affected portion of the vestige[2].

In principle, the waveform distortions can be calculated once the transmitter and receiver characteristics are known, and this has been done by means of the simulation described next. However, it is also necessary to confirm these calculations by measurements on 'real' equipment. The remainder of this Paper thus concentrates on results of practical measurements.

4. Simulation of the Effects of Vestige Reduction

The object behind the simulation was to discover the worst likely distortion that could occur as a result of reducing the vestige width. It was assumed that the receiver had a Nyquist filter making full use of the original PAL-I vestige; that is, the response was zero at fv – 1.25 MHz, rising uniformly to unity at fv + 1.25 MHz. The transmitter response was taken to be flat down to fv – 0.75 MHz and zero below that. By summing the contributions in the way described in the previous section, the overall system response could be calculated. **Figure 3** below illustrates this:

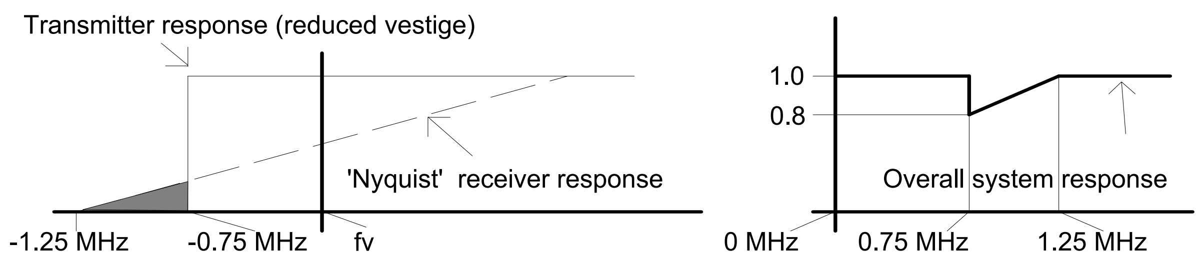

Figure 3: The System Response Resulting from a Simulated Reduction of Transmitted Vestige

[1] Strictly this is only true for synchronous receivers and linear phase systems.

[2] For instance, the 2T pulse has a nearly flat spectrum up to 2.5 MHz. (Beyond this frequency, the spectrum falls away to nearly zero at 5 MHz.) In contrast, the response error at the output of the receiver is appreciable over a region of less than 0.5 MHz.

The next stage was to define the video waveform to be passed through the system. A 2T pulse was selected[3], as this would allow ready comparison with practical laboratory measurements.

A Fourier transform was then carried out on the waveform, thus converting the time domain information into the frequency domain. In this form, the information could be multiplied by the amplitude response already obtained. Finally, an inverse Fourier transform was performed, and the distorted 2T pulse recovered. **Figure 4** below shows the original and distorted 2T pulses superimposed:

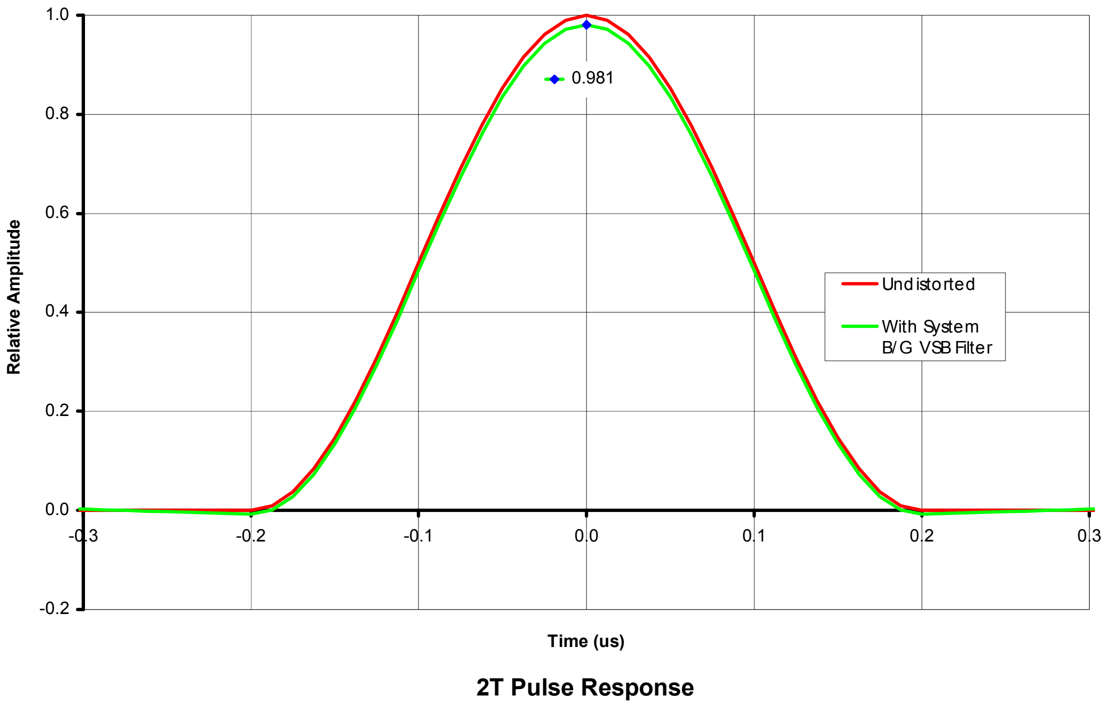

Figure 4: The Distorted 2T Pulse Resulting from Reduction of the Transmitted Vestige

The simulation shows that distortion of the 2T pulse is small: the only significant effect of reducing the width of the transmitted vestige is to reduce the pulse amplitude by about 2%. In practice, with a 'real' transmitter VSB filter, the errors would be even smaller. Probably, other sources of distortion within the transmission chain would dominate.

5. Arrangements for Assessing the Effects of PAL-I Vestige Reduction

A slightly modified Rohde and Schwarz IF Modulator and UHF Upconverter were used for assessing the practical effects of vestige reduction. **Figure 5** overleaf illustrates the arrangements.

The Rohde and Schwarz IF Modulator accepts standard PAL-I video and would normally mix this with an internally generated 38.9 MHz local oscillator. The resulting double sideband IF signal then passes through a VSB filter. In this case, however, an external local oscillator is used, which allows the IF carrier frequency — and hence the width of the vestige passed by the VSB filter — to be altered. The Modulator contains internal VSB filtering which conforms to the minimum attenuation requirements of the System I specification. However, an external, 'professional quality' SAW filter may be used in its place, and this provides a much faster out-of-band roll-off.

[3] An undistorted 2T pulse comprises a single cycle of raised cosine, with 200 ns half-amplitude duration. The simulation did not include the effects of 5.5 MHz low-pass filtering.

The UHF upconverter is a standard Rohde and Schwarz unit. Its local oscillator frequency is continuously variable, *and has to be offset by an amount equal to any offset applied to the IF oscillator if the UHF output frequency is to remain correct*. The UHF output is then fed to television receiver being assessed. Each receiver provides a baseband output, so that measurements can be made on the demodulated video signal.

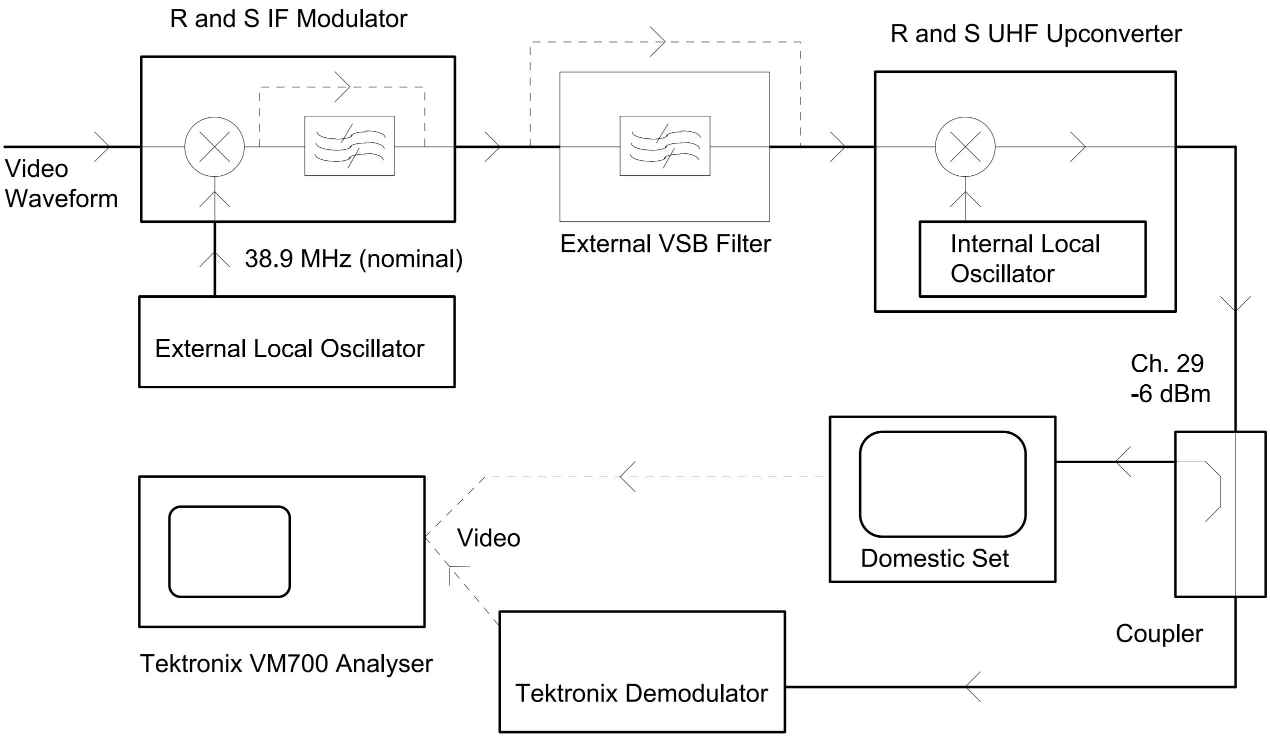

Figure 5: Arrangements for Assessing the Effects of PAL-I Vestige Reduction

Figure 6 overleaf shows the overall response of the modulator when used with the two alternative VSB filters.[4] Also shown is the present mask for System I. Note that the vision carrier at IF is at its nominal frequency, and so the width of the vestige is the full 1.25 MHz.

A response conforming to the proposed System B/G standard[5] is achieved by moving the vision IF carrier 0.7 MHz towards the edge of the vestige in the manner previously mentioned. The result is shown in **Figure 7** overleaf; also included is the version of the System B/G mask which it is proposed to adopt for PAL-I transmissions[6].

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[4] The response was obtained by using the standard video waveform for sideband analysis; that is, a 700 mV peak-to-peak tone gated on to a 350 mV luminance pedestal with mixed syncs. This waveform was applied to the input of the modulator, and a spectrum analyser used to determine the sideband level at the output of the VSB filter. The notional sideband level before VSB filtering is −17 dB relative to vision peak sync power, and this figure was used as the reference when plotting Figure 5.

[5] Provided the SAW VSB filter is used. The LC filter within the Rohde and Schwarz modulator is not sharp enough to give a response meeting System B/G requirements, whatever IF carrier frequency is used.

[6] The original System B/G mask did not include the requirement for the sideband level to be below −30 dB at 1.4 MHz below vision carrier.

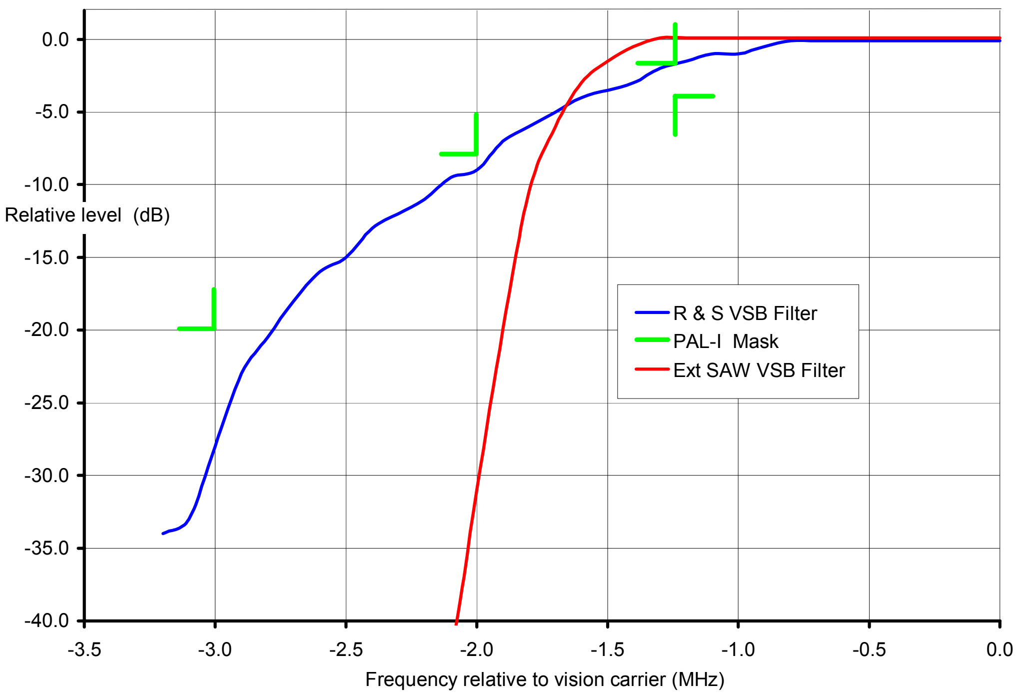

Figure 6: Sideband Response of the Modulator with the Two Alternative VSB Filters[7]

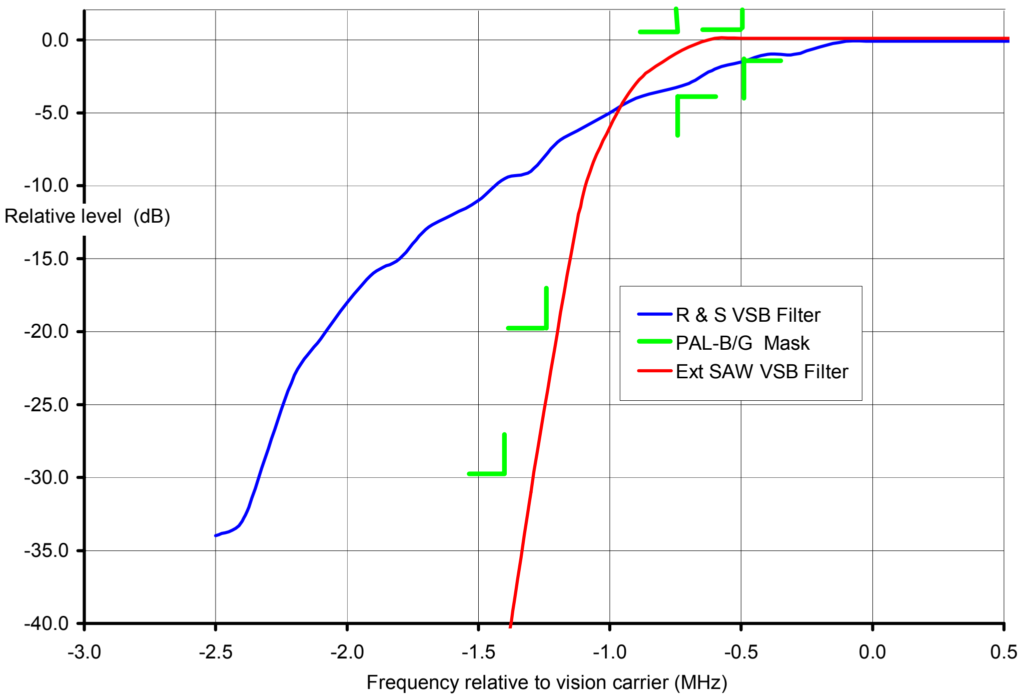

Figure 7: Sideband Response of the Modulator when Optimised for System B/G

[7] It will be noticed that the SAW filter has less attenuation at −1.25 MHz than specified by the PAL-I mask. This is because the filter was originally intended for use in television transposers, and not in transmitter modulators. However, the use of such a filter during the tests described ensured that the output of the PAL-I demodulator was as nearly ‘perfect’ as possible; thus errors caused by the introduction of the System B/G filter were highlighted.

6. Characteristics of the Receivers Used

Four different receivers were used during the tests to assess the effect of reducing the transmitted vestige. These were intended to be representative of the range of equipment likely to be encountered. However, it was obviously necessary for each receiver to possess a baseband video output — not a feature provided by all domestic models. Comments about the four receivers used are given below; their Nyquist filter responses are shown in **Figure 8**:

- ***A 'professional' grade 1 receiver.*** This is the well-known Tektronix demodulator which is often used as a standard for assessing the quality of PAL-I signals. It includes a SAW Nyquist filter with a very closely specified response.
- ***A 'top-of-the range' domestic receiver.*** This model includes 'extras' such as Teletext and Nicam sound. The Nyquist response is obtained with a SAW filter, as it is in the 'professional' receiver, but not so precisely. When measurements were first made, a fault was suspected, as the high 2T pulse-to-bar ratio suggested that the vision carrier was not positioned at the half-amplitude point of the Nyquist response. However, a second receiver by the same manufacturer was tested, with similar results. It is possible the receivers included some high-frequency 'lift' in the video stages.
- ***A 'budget' domestic receiver.*** Although this does not have all the facilities of the previous receiver, its RF circuitry is probably very similar — in fact, its performance appeared to be slightly better. Again, the Nyquist response is obtained with a SAW filter.
- ***An elderly receiver with LC Nyquist filtering.*** This was not designed for the domestic market, and does not include a picture tube or loudspeaker; it simply provides baseband audio and video outputs. However, its RF circuitry is representive of the techniques used in the early 1970s. Some alignment was necessary to give the receiver a satisfactory Nyquist response.

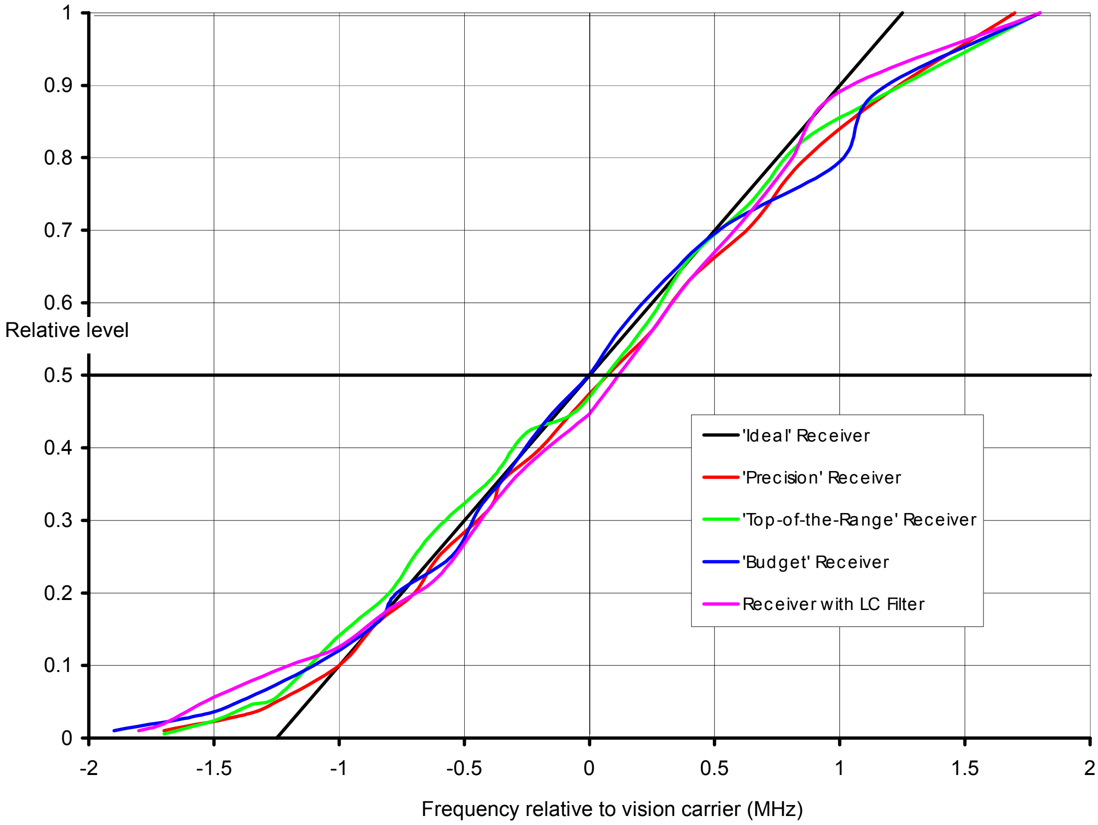

Figure 8: Nyquist Filter Responses of the Receivers Tested

The most obvious feature of Figure 8 is that all receivers tested make use of the full width of the System I vestige, although there are some departures from an ideal Nyquist response[8]. (In principle, the Nyquist filters could have been designed with a steeper slope. If this had been done, reducing the width of the vestige would have less effect on the demodulated outputs.)

7. Measurements Made on the 2T Pulse Response

Firstly, accurate measurements were made using the Tektronix precision receiver. The two modulator VSB filters were used in turn, and the 2T pulse parameters plotted as a function of vestige reduction. **Figure 9** below shows the results for the 2T pulse-to-bar ratio:

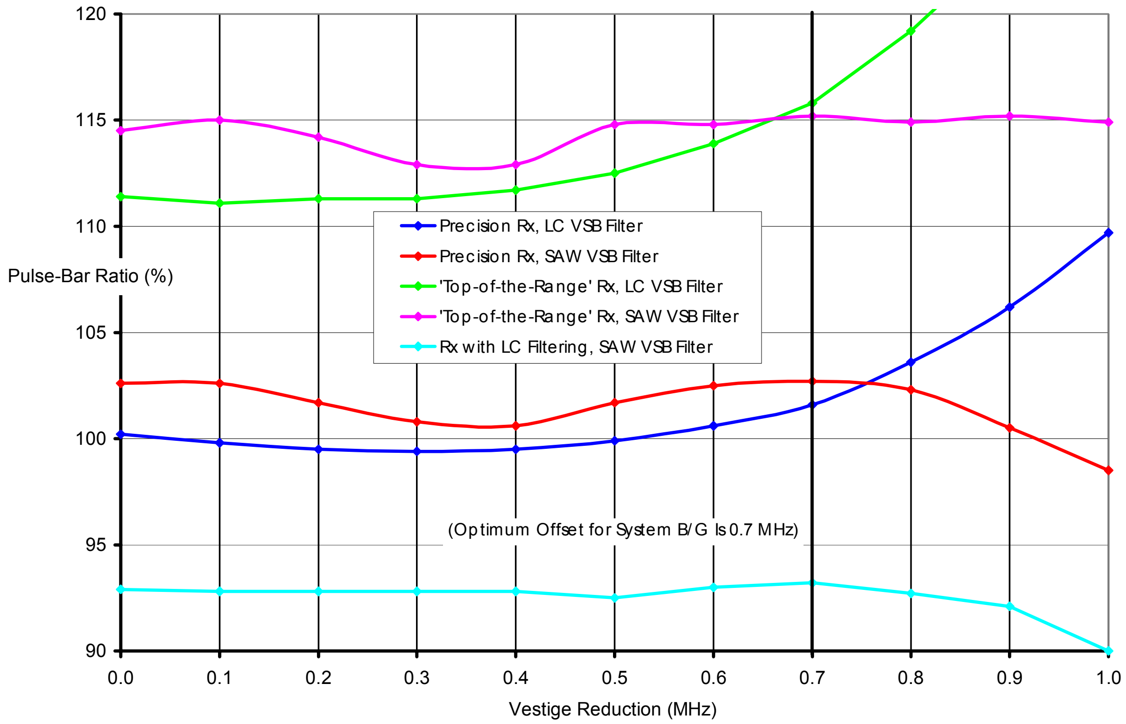

Figure 9: 2T Pulse-to-Bar Ratio as a Function of Vestige Reduction

As expected, the errors are quite small, provided the offset is limited to 0.7 MHz — the value at which the modulator response is closest to the System B/G ideal. At larger offsets, the SAW VSB filter tends to *reduce* the pulse-to-bar ratio, because the dominant effect is the reduction in level of the lower sidebands. However, the LC VSB filter, with its slower roll-off, tends to *increase* the pulse-to-bar ratio. This is because the dominant effect is then the reduction in vision carrier.

Similar trends can be seen with the domestic receivers, and the performance of the 'top-of-the-range' model is also shown in Figure 9. The high pulse-to-bar ratio has been discussed in Section 6. Finally, the performance of the receiver with LC filtering is given. Although its Nyquist filter showed the greatest departures from an ideal response, the variation in pulse-to-bar ratio is similar to that noted for the other receivers.

Figure 10 overleaf gives the corresponding 2T pulse 'k' ratings. There are no great surprises here. Poor figures here would only have been likely if large group delay errors had been present in the system; in fact, most of the filtering was notionally linear phase.[9]

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[8] That is, one which is skew symmetrical about the vision carrier.

[9] The exception being the LC Nyquist filtering within the last receiver.

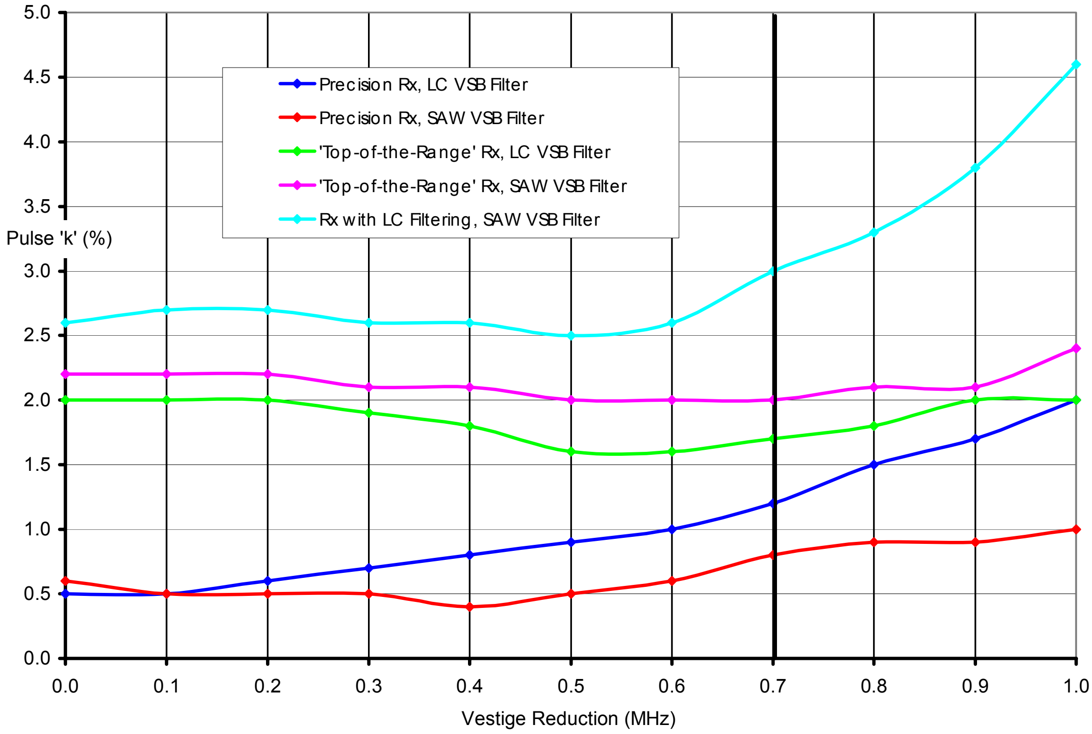

Figure 10: 2T Pulse 'k' as a Function of Vestige Reduction

8. Video Waveform Distortions

At the same time the above measurements were taken, prints were made of the 2T pulse and bar within the insertion test signal; a selection is included at the end of this report. **Prints 1**, **2** and **3** show the output of the Tektronix precision receiver, with the SAW VSB filter being used. Print 1 illustrates the good performance of the equipment when the vision IF is at its standard frequency of 38.9 MHz. Print 2 shows that the performance remains good with an IF of 39.4 MHz — a vestige reduction of 0.5 MHz. Finally, Print 3 indicates that, at a vestige reduction of 1 MHz, the distortion is becoming measurable. Even then, however, the 2T pulse 'k' is within 1%.

Prints 4, **5** and **6** illustrate what may be expected from domestic television equipment. These prints were taken under the same conditions as for the first three, except that the domestic 'top-of-the-range' model was substituted for the precision receiver. The inherent waveform distortions are now much greater than the small distortions resulting from the reduction in vestige width.

9. Ceefax Eyeheight Measurements

Reduction of the System I vestige was not expected to give rise to problems with the decodability of the Ceefax (Teletext) data; the work described above indicated that waveform distortions — and hence eyeheight reduction — would be small. However, to confirm this, measurements of the Teletext eyeheight were made at the output of each of the four receivers. Once again, the Tektronix VM700 was used as the analyser; it displays the eyeheight as a percentage of the difference between '0' and '1' levels. In fact, two figures are given — that at the mid-point of the eye, and that at the timing reference. **Table 1** overleaf quotes both figures for all four receivers at vestige reductions of 0, 0.5 MHz and 1 MHz. The SAW VSB filter was used throughout.

Although there are variations between the receivers, the vestige width makes very little difference. In all cases, the eyeheight is more than adequate for error-free decoding.

Receiver	Ceefax Eyeheight (%) at Various VSB Reductions					
	0 MHz		0.5 MHz		1 MHz	
	Reference	*Mid-point*	*Reference*	*Mid-point*	*Reference*	*Mid-point*
Precision[10]	89.7	93.8	91.0	95.0	84.7	89.4
Top-of-the Range	81.7	86.2	79.3	85.6	80.9	85.0
Budget	78.5	78.8	77.8	83.1	79.7	81.9
With LC Filter	66.6	78.8	64.2	78.1	65.9	77.5

Table 1: Ceefax Eyeheight Measurements

10. Subjective Picture Quality

Picture quality was assessed with a variety of material, but mainly the testcard shown in **Photograph 1**, at the end of this report. It was selected because the sharp vertical edges of the crosshatch pattern would tend to show up any distortions resulting from vestige reduction. In fact, the subjective picture quality remained good as the vestige was reduced, even when large waveform distortions could be measured with the VM700 Video Analyser. Generally, the most noticeable effect was that the picture became noisy for extreme vestige reduction[11]. The mechanism responsible was loss of vision carrier and *upper* sidebands, not distortion of the waveform. No loss of quality was ever visible with the vestige set to conform to the proposed System B/G mask.

11. Conclusions

The work described above has demonstrated that reducing the PAL System I vestige from 1.25 MHz to 0.75 MHz will not cause problems in receiving PAL System I transmissions. A simulation has shown that, if the transmitter possesses the most extreme characteristics allowed by the proposed ‘System B/G’ spectral mask, the 2T pulse amplitude is reduced by about 2%. Other video distortions are unlikely to be significant.

Practical laboratory measurements have confirmed that 2T pulse amplitude errors remain within 2% as the vestige is reduced from its present value to that proposed. This is true for a precision receiver and for a variety of domestic receivers, provided that a sharp cut-off SAW VSB filter is used. Such a filter is essential, in any case, if the proposed transmitter spectrum mask is to be met. Even so, the errors are not great when a traditional slow cut-off filter is substituted for the SAW filter.

For domestic receivers, the imperfections resulting from a reduction in vestige width are negligible when compared with those caused by mechanisms such as imperfect AFC and inexact Nyquist filter response.

No significant loss of subjective picture quality or Ceefax performance is attributable to the vestige reduction.

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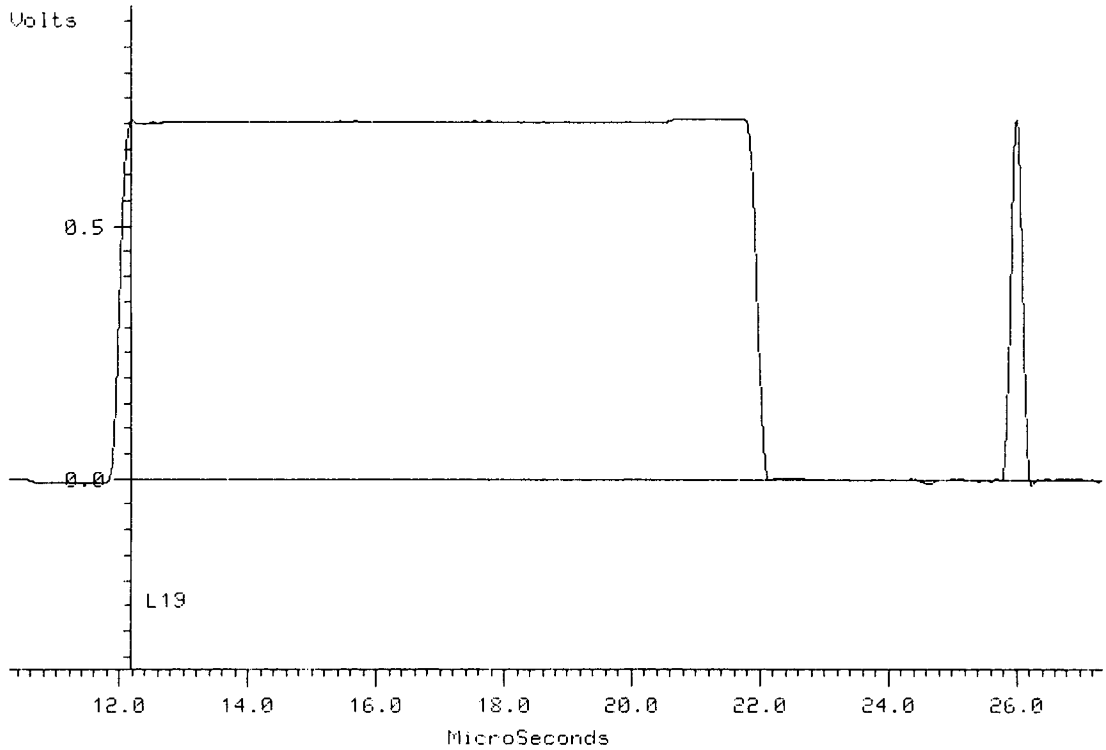
[10] The precision receiver used here was *not* the same as that used for the previous measurements, since the original had developed a fault. However, these eyeheight measurements should still be representative.

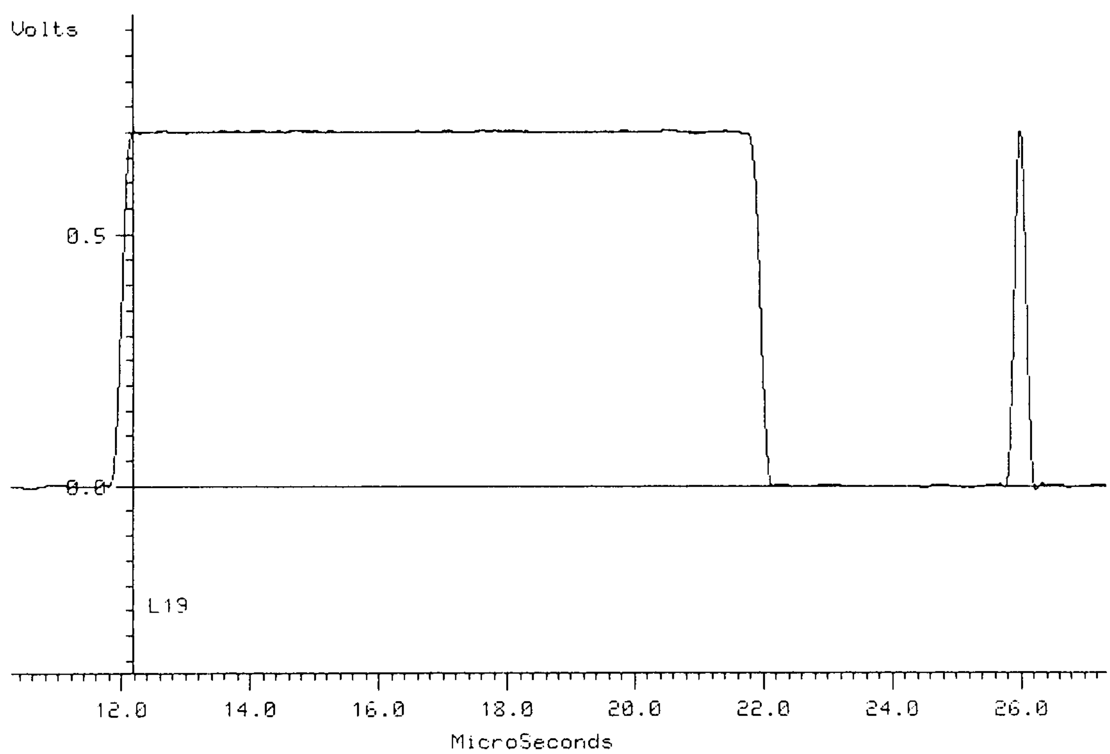
[11] Or, rather, for a frequency shift of the modulator IF local oscillator in excess of 1.25 MHz. When the frequency shift is increased beyond this value, the carrier level falls rapidly, particularly when the SAW VSB filter is used.

12. Acknowledgements

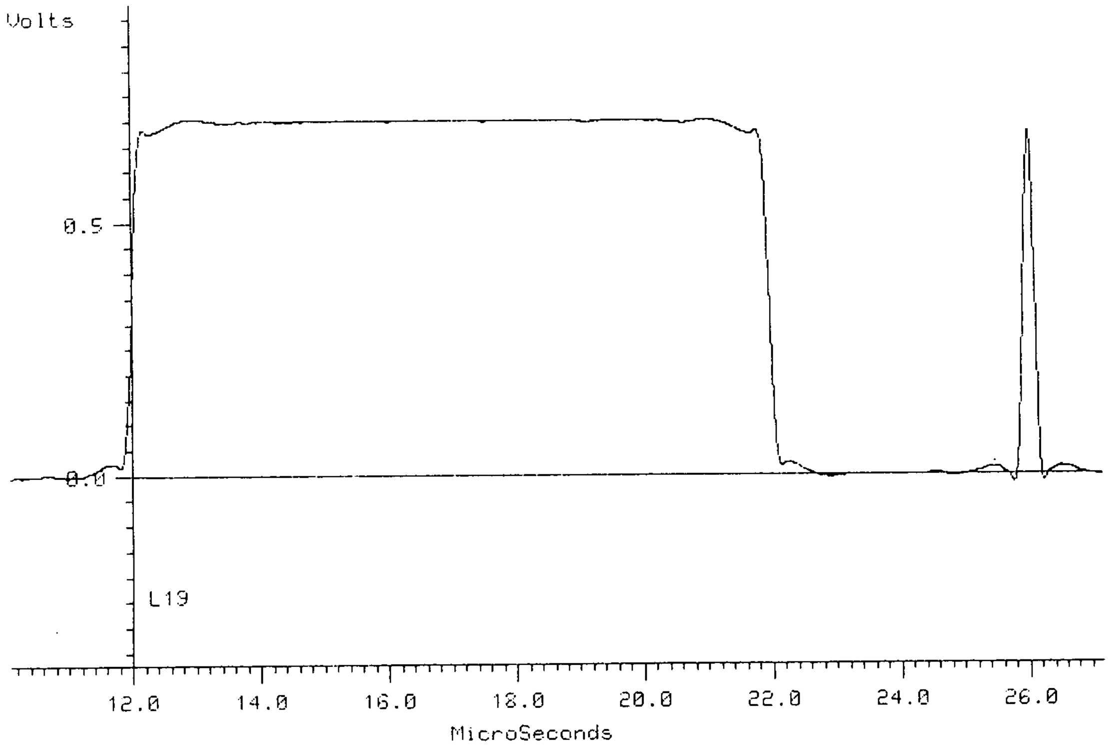
Thanks are due to Mike Ellis and Jon Stott for their advice on the computer simulation, to John Salter for helping with the test set-up, and to Malcolm Williams for helping with the laboratory measurements.



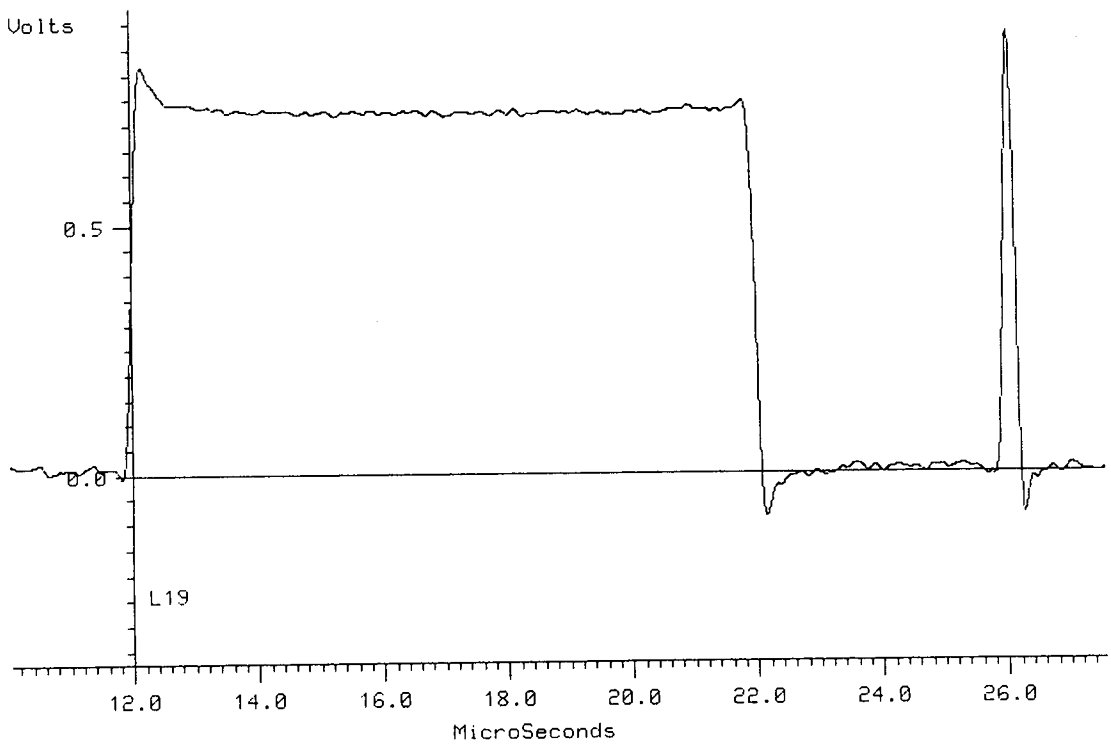
Print 1: 2T Pulse and Bar at Output of Precision Receiver
(No Vestige Reduction)



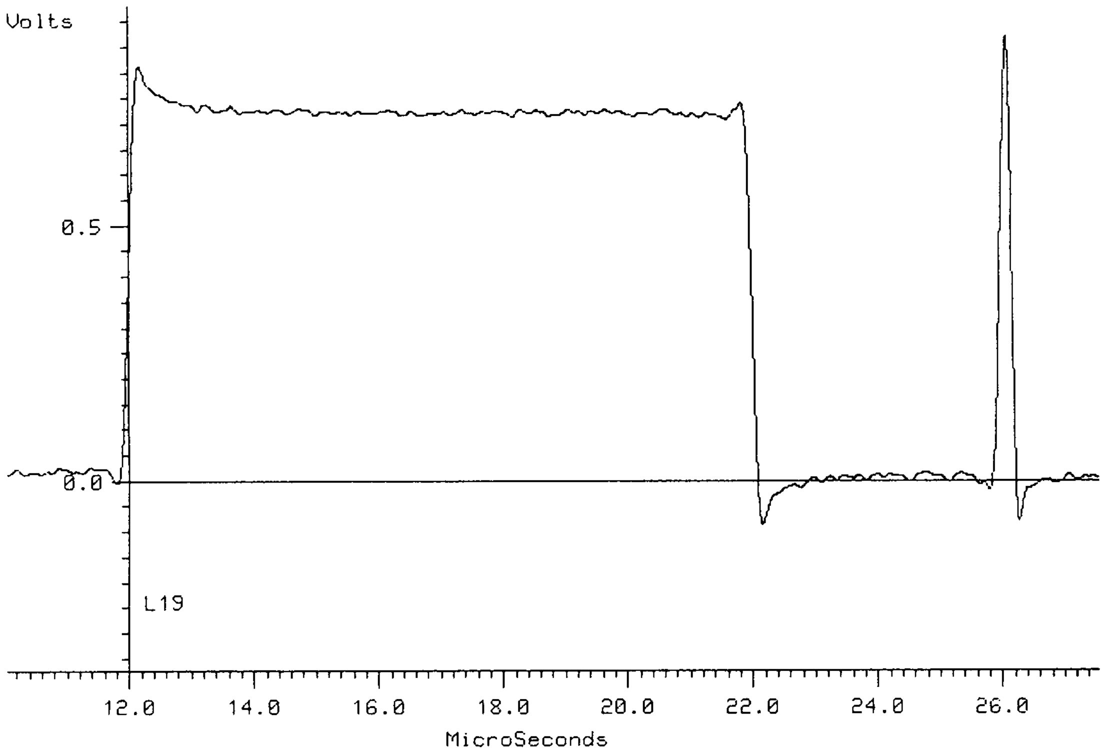
Print 2: 2T Pulse and Bar at Output of Precision Receiver
(0.5 MHz Vestige Reduction)



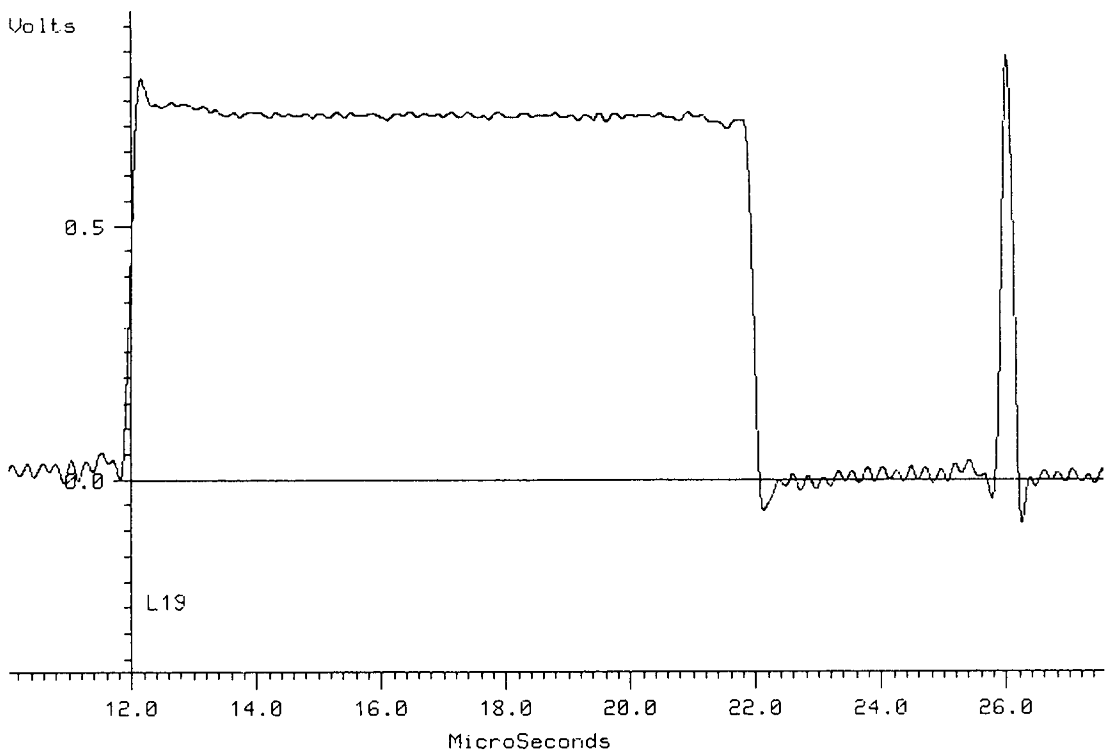
Print 3: 2T Pulse and Bar at Output of Precision Receiver
(1.0 MHz Vestige Reduction)



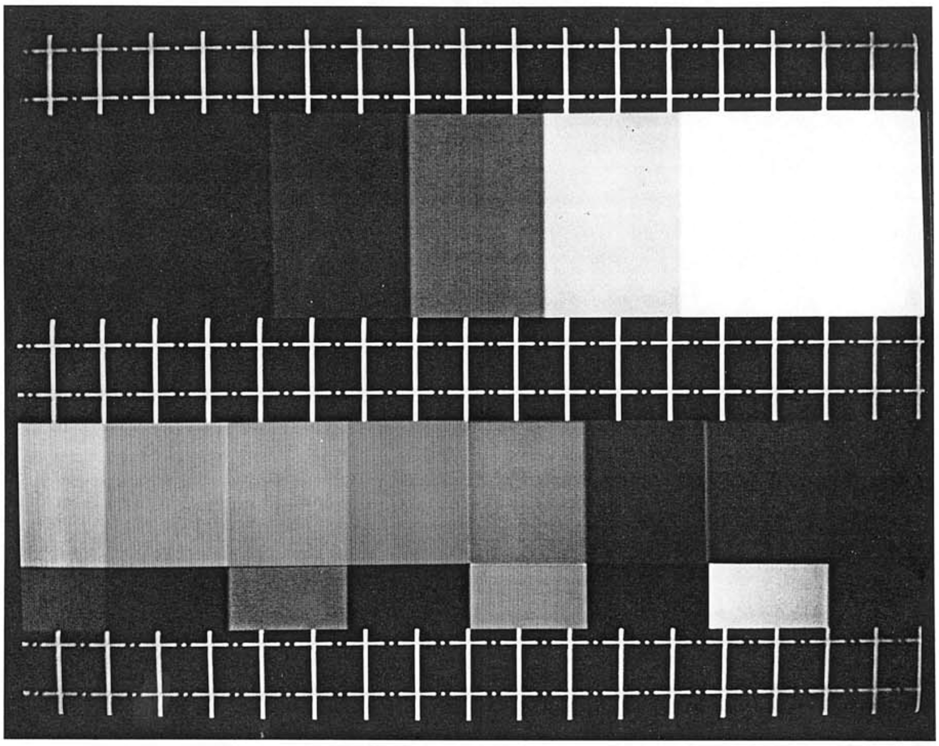
Print 4: 2T Pulse and Bar at Output of Domestic Receiver
(No Vestige Reduction)



Print 5: 2T Pulse and Bar at Output of Domestic Receiver
(0.5 MHz Vestige Reduction)



Print 6: 2T Pulse and Bar at Output of Domestic Receiver
(1.0 MHz Vestige Reduction)



Photograph 1: Testcard Used to Assess Subjective Picture Quality