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FLICKER IN TELEVISION DISPLAYS

A Review

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SUMMARY

Minimising flicker is not always a primary consideration when specifying television displays, or the conditions under which they will be viewed. Consequently excessive flicker may be experienced.

A consideration of the factors which affect the perception of flicker suggests the following measures can usefully be applied when flicker is found to be a problem:-

- Reduce the contrast of the display.
- Reduce the overall brightness of the display.
- Ensure that ambient lighting is not too bright.
- Ensure that the display does not subtend too large a visual angle by allowing a reasonable viewing distance; a distance of four to six times the picture height is recommended. Do not use a monitor larger than necessary.
- Ensure that the black-level of the display is correctly set so that black areas of the picture are reproduced as black rather than mid-grey.
- Where a number of monitors are used simultaneously their scans should, ideally, be synchronised.
- If at all possible, displays positioned such that they are in peripheral vision for much of the time should be avoided or switched off when not in use.
- Flicker is more likely to be a problem for younger persons.

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Display brightness and contrast, ambient lighting and viewing distance are constrained by practical considerations. A display must be bright enough and have enough contrast to be intelligible; ambient lighting must be bright enough to allow concurrent tasks, such as paperwork or working the controls of a machine. Viewing distance should not be increased beyond that from which an observer cannot resolve the detail in the display.

The flicker generated can be minimised by the design of the display:-

- A long persistence phosphor will reduce flicker, but will also cause blurring of moving pictures. For many applications this may be unacceptable.

- Interlace is best avoided for field rates around 50Hz, particularly where short viewing distances are unavoidable.

- It is possible to build displays to operate at field rates greater than 50Hz. These are a good solution for computer displays, but present a problem for television systems; the entire system must operate at the higher field rate and will thus be incompatible with existing equipment. Ancillaries working at increased field rates are likely to be costly.

- In the near future it will be possible to display video signals from conventional television equipment on high scan rate monitors by employing digital signal processing. However, to be really effective scan conversions must be motion adaptive and at the moment this is not a trivial problem.

There is some evidence to suggest that the human visual system responds to intermittent illumination at frequencies above flicker fusion. However an experiment by the authors found no major differences in an observers performance of a visual search task at three different field rates; 50, 80 and 100Hz.

No conclusive evidence has demonstrated that flicker causes eyestrain or has any long term, adverse effects on health, although most people would agree flickering displays are unpleasant to work with.

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1.0 Introduction.

It is well known that the image displayed on a cathode ray tube (CRT) is generated by bombarding a phosphor coated screen with an electron beam. In response, the phosphor emits light and, so that the whole screen can be addressed, the electron beam is made to scan. The light emitted by the phosphor decays rapidly and exponentially once the beam has passed, but if the rate of scanning is high enough the whole screen will appear to be equally illuminated. This is a property of the human visual system, not of the display (unless the phosphor is of exceptionally long persistence) and is commonly called the persistence of vision. The process is largely equivalent to a low-pass filtering in the temporal domain, but like all things human, the filter characteristics are somewhat variable, and dependent on many factors.

A linear scanning system can be defined in terms of L/f/i:1 where L=the number of lines scanned, f=the the field rate and i= the interlace factor. European television systems (PAL and SECAM) scan a frame of 625 lines, and each line is refreshed 25 times per second. In the USA (NTSC) 525 lines are scanned 30 times per second. To improve the effective refresh rate a 2:1 interlace is used whereby each frame is divided into two fields. One field contains all the odd numbered lines, the other all the even numbered lines. These are then scanned alternately so that one of an adjacent pair of lines is refreshed every 50th, or in the USA 60th of a second. If the screen is viewed from a distance at which it is not possible to see the individual lines, then the whole screen appears to be refreshed f times a second whilst the actual refresh rate is f/i. Thus PAL and SECAM use a 625/50/2:1 scanning system while NTSC uses 525/60/2:1.

It is quite clear both from experience and the vast range of psychophysical data available that television displays using these standards will appear to flicker under a variety of viewing conditions. The flicker is usually made up from three components; Large, bright areas will flicker at the field rate; if the line structure is visible, a patterned flicker at the frame rate, known as interline flicker, will be evident, and picture detail which excites only a single scan line will flicker at the frame rate. (Although strictly speaking, the second of these is best described as jitter rather than flicker.) Many people find this annoying, and sometimes extremely disturbing. If television is used intensively for remote viewing the annoyance could be considerable and excessive flicker may, in addition, have more serious effects.

The first section of this report reviews the factors which affect the perception of flicker, and how these may be used to optimise viewing conditions. The second section looks at other ways of reducing flicker and the third discusses whether flicker has any adverse effects on health or visual performance.

1.1 Factors Affecting The Perception of Flicker.

From the enormous number of psychophysical experiments on flicker, it is evident that there are a large number of variables and that the details of the experimental design are fairly critical to the outcome. Therefore a detailed summary is difficult.

Many results cannot be applied to television displays in a quantitative way; traditional flicker studies have used uniform fields and sinusoidal or squarewave modulation, sometimes at very low levels, whereas the flicker in television pictures is spatially and temporally complex, usually at high levels of modulation. However it is likely that the results can be applied in a qualitative way.

If the human visual system is considered as a temporal, low-pass filter, then flicker sensitivity could be characterized by plotting the filter´s modulation transfer function. For an electronic or mechanical filter this would normally be done by measuring the output for a given input, but in the case of the human filter it is not possible to measure the filter output directly. Hence, the input required for a constant output is measured; if the filter has a linear amplitude response this is entirely equivalent. The level of constant output is the threshold for which a flickering source first appears to be steady. The frequency for a particular depth of modulation at which this point is reached is called the Critical Fusion Frequency (CFF).

Figure 1 shows three typical response curves at different retinal illuminances, determined by de Lange (1958), after whom such curves are commonly known. However, since the linearity of the human filter is questionable, such curves can only loosely be described as the response curves of the filter.

The unit of retinal illumination, the Troland, is the product of field luminance in cd/sq m and pupil area in sq mm. The curves in figure 1 are, in fact, for a complex waveform, so modulations of up to 200% are possible. Generally, CFF ranges from a few Hz up to around 90 Hz.

The main factors found to affect CFF are (mostly from Brown 1965):-

a) Field size.

There is a linear relationship between CFF and the log of field size for a wide range of luminance levels; CFF increases with the visual angle subtended. This is often known as the Granit-Harper law and has been verified for fields of up to 50 degrees of visual angle and centred at retinal locations up to 10 deg away from the fovea.

The visual angle subtended by a display monitor depends on the viewing distance and the size of the monitor. A monitor of diagonal d, viewed from a distance of v will subtend an angle of:-

$$2 \text{ Arctan } (d/2v) \text{ degrees}$$

e.g an industry standard, 46cm (19 inch) monitor viewed from 1.2m will subtend an angle of 22 degrees.

b) Field luminance.

Over the range for which the Granit-Harper law operates, CFF increases linearly with the log of retinal illumination. Figure 2 shows this for fields of 6 and 19 degrees, fixated centrally. 10 Hz for each tenfold increase luminance is fairly typical. This is sometimes known as the Ferry-Porter law.

At high retinal illuminance the curve flattens out. In figure 2 this happens at about 3200 Trolands. If the pupil diameter of the eye is taken to vary between 2mm and 8mm, this would correspond to a screen luminance of between 16 and 256 cd/sq m. Pupil diameter is determined by a number of factors other than the amount of incident light. It is therefore not clear whether the upper limit, above which field luminance will have little effect on CFF, lies within the range of screen luminances commonly found in TV displays, where maximum white level is typically in the range 60-150cd/sq m.

At low luminances a second branch to the curve develops. This is assumed to be where only rod photo-receptor cells are stimulated and is outside the luminance range likely to be encountered in television displays.

At flicker frequencies above fusion the perceived brightness is proportional to the time averaged luminance of the flickering field. This is the Talbot-Plateau law and the implication for television is that CRTs with short persistence phosphors have to produce much higher peak luminances than long persistence tubes to achieve the same apparent brightness.

c) Retinal location.

For small sized fields CFF decreases with increasing distance from the fovea, but for larger fields (Granit and Harper suggest >2 degrees) the reverse is true and CFF tends to be higher in peripheral vision. The latter case is applicable to CRT displays.

For this reason, flicker is likely to be more of a problem for a bank of display monitors, where there will inevitably be one or more monitors in the field of peripheral vision. In such cases it is preferable to have the monitor scans synchronised to eliminate the possibility of beat frequencies becoming noticeable.

Similarly, for a monitor which subtends a large visual angle (say >30 degrees), the corners will be well into peripheral vision and may flicker even though the centre of the screen appears steady. Likewise, the centre of the picture may flicker when the extremes are viewed; the flicker will move around in the opposite direction to area of interest.

d) Adapted state of the eye

As the eye becomes more light adapted (i.e. adapted to brighter light) then CFF increases. Therefore ambient lighting and the nature of the immediate surrounding field become important. However when the display subtends a large visual angle then the luminance of the display is probably the most important factor in determining the adapted state.

e) Age

Like most aspects of human performance, CFF declines with age; older persons are less sensitive to flicker.

f) The mark:space ratio of the flicker

A decrease in mark:space ratio will lead to a decrease in the perceived brightness. If the average luminance is held constant then CFF increases very nearly in proportion to the log of the relative duration of the dark interval. This is entirely consistent with the considerations in the next paragraph.

g) The flicker waveform.

CFF depends on the amplitude of the fundamental Fourier component of a complex waveform if the first and higher harmonics are outside the pass-band of the human visual system filter or at least highly attenuated (de Lange 1958). This is likely to be the case for television where the fundamental is not lower than 25Hz.

However the amplitude of the fundamental can be very different from the waveform´s peak to peak amplitude. For a square wave the fundamental is 1.27 times the peak to peak amplitude, and for the waveform of a CRT with a short persistence phosphor, the fundamental can be as high as twice the peak to peak amplitude of the complex waveform, and thus should have a higher CFF than a sinusoidal waveform of the same frequency and peak to peak amplitude.

h) Spatial frequency

The human visual system does not process spatial and temporal information entirely separately; an image stabilised on the retina with respect to eye movement will rapidly appear to fade, but under intermittent illumination the visual sensation remains. (Ditchburn et al 1959)

Robson (1966) has measured the variation of temporal modulation sensitivity with spatial frequency and its complement, the variation of spatial modulation sensitivity (i.e the ability to distinguish a grating from a uniform field) with temporal frequency. Figures 3 illustrates this, replotting from Robson´s data, modulation sensitivity as a function of both spatial and temporal frequency.

Similarly, Graham and Landis (1959) have demonstrated a relationship between CFF and spatial frequency, for sinewave gratings with squarewave temporal modulation. CFF exhibits a minimum when plotted against spatial frequency and is depressed by about 10Hz for a spatial frequency of 7.1 cycles per degree, relative to a field without striations. Thereafter CFF rises to slightly above its initial value as spatial frequency is increased to 20 cpd.

Quantitatively, Robson´s results, using a field of only 2.5 by 2.5 degrees and modulation considerably less than 100%, are of dubious applicability to television displays. Similarly, but to a lesser extent those of Graham and Landis, but the existance of such a spatio-temporal interaction may explain the common observation that an interlaced picture has subjectively less vertical resolution than a non-interlaced one with the same number of lines. It has been suggested that at a field rate of 50Hz resolution is reduced by a factor of 0.8, at 60 Hz the factor is 0.87, and is 0.95 for 75Hz.

1.2 The Effects of Line Interlacing on Flicker

The idea behind line interlacing is to enable the transmission of a larger number of lines for a given bandwidth and flicker than would be possible with a sequential scan. For instance, 625 lines scanned as 625/25/1:1 would flicker considerably more than 625/50/2:1 but use no less bandwidth. However, interlace has the consequences that picture detail which excites only single TV line will flicker at half the field rate, that bright areas of the picture will exhibit a patterned flicker and horizontal edges will hop up and down, again at half the field rate.

White (1978) showed that subjectively there is a rapid diminution of picture quality once the interlaced line structure becomes visible. He has also pointed out, that from the often recommended viewing distance of 6 times the picture height, a person with 6/6 or better visual acuity should be able to resolve the line structure of a 625 line display.

In addition, it is our opinion that an interlaced display viewed peripherally flickers more than the equivalent sequentially scanned display; here the line structure cannot be resolved, but perhaps there is a greater spatio-temporal interaction than for foveal vision. This, together with the observation in the previous section, that the improvement in resolution afforded by interlacing is not as large as expected, suggests that all in all the benefits of line interlacing at 50 or 60Hz are minimal.

1.3 The Prediction of Flicker Thresholds for a CRT from a Modulated Homogeneous Field

a)Van der Zee, Roufs and van der Meulen

An experiment by van der Zee, Roufs and van der Meulen (1983) explicitly compared flicker thresholds for a modulated homogeneous field with those for a CRT display. The aim was to resolve the question of the reliability in predicting CRT flicker from experiments which used homogeneous fields.

The homogeneous stimulus was generated by a fluorescent lamp behind an almost perfect light diffusing glass. The CRT displayed a plain raster of 2287 active lines on a screen 21cm by 30cm, and was viewed from a distance of 50cm. The screen therefore subtended approximately 12 by 16 degrees of visual angle. Several levels of screen luminance were used, and frequencies from 120Hz down to 15 Hz. Frame rates between 60Hz and 120 Hz used a 2:1 interlace while the lower frame rates, generated by skipping fields, were non-interlaced and contained only half as many lines. The modulation depth of the homogeneous field was varied by varying the mark:space ratio of the drive to the fluorescent tubes, and for the CRT by optically superimposing the homogeneous field whilst varying the DC drive to the tubes.

The results are published only for 2 luminance levels, 50 and 100cd/sq m. In both cases the maximum frequency at which flicker was visible was a little over 50 Hz, and so used a non-interlaced format. The plots of modulation depth required to see flicker on 50% of the presentations vs frequency are very similar for homogeneous and non-homogeneous fields at frame rate above 15 Hz, but CFF for the homogeneous field is always higher. However the difference between the CRT display and the homogeneous field is of the same magnitude as the difference between subjects, and although van der Zee et al. concluded that it is safe to estimate flicker thresholds for CRTs from modulated homogeneous fields, the comparison is not complete. No results are given for CRT scans which used interlace (which may well have behaved differently), and the maximum modulation depth used was 1. At this depth of modulation the output from the lightbox would have been equal to the mean light output from the CRT, and therefore untypical of television viewing conditions.

b) Chaplin and Freemantle

Chaplin and Freemantle (1987) of IBM UK Labs have used an optical sensor, not unlike a spot photometer with a field of view of about 2 degrees, connected to a computer to extract the temporal Fourier components from different VDU displays. The results could be displayed graphically, overlaid with scaled and normalised subjective flicker fusion curves for various target sizes. Depending on whether the fundamental component cuts the flicker fusion curves, the perception of flicker can be predicted. The reference point which links the fusion curves with the Fourier analysis is a modulation of 200cd/sq m peak to peak. The ordinate is plotted in dB and so this point is 0dB. Figure 4 shows an example.

The problem, of course, is in finding appropriate subjective fusion curves. Chaplin and Freemantle chose to collect their own data from 100 subjects using an array of flashing LEDs. The average intensity was 150cd/ sq m and three field sizes were used, 5, 15, and 20 degrees. The data are included in their computer programme and intended to represent the upper sensitivity of 85% of the population.

However, in collecting the subjective data no account has been taken of the effects of ambient lighting level or any additional effects due to patterned flicker. The conclusions of van der Zee et al are assumed to be universally true and in addition, it is not clear how these flicker fusion data should be applied to VDUs which cannot achieve a mean luminance 150 cd/sq m. Therefore, for all the sophistication of the objective measurement, it would seem that the final predictions are only a gross approximation.

1.4 Optimum Viewing Conditions.

A consideration of the factors in section 1.1 suggests that the optimum viewing conditions to minimise flicker would involve viewing small dim monitors, from long distances in dimly lit rooms. In practice, these factors have to be balanced against the need to be able to resolve enough detail in the picture and the need to carry out concurrent tasks, such as paperwork. In addition, were it not for the flicker, large bright screens would be much preferred.

Some guidelines suggested by Cakir, Hart and Stewart (1979) for the use of computer VDUs are as follows:-

Contrast ratio characters:background, 10:1

Contrast ratio background:surrounding, 1:3

Character luminance of 80-150cd/m^2

Screen background luminance of 15-20 cd/m^2

Ambient light level of 300-500 lux

Display subtends 20 degrees

Although there are differences between VDUs and television displays, namely that computer VDUs often use long persistence phosphors and non-interlaced scanning, and are frequently required to display only two brightness levels, character and background, these viewing conditions could be applied to television displays. However a maximum contrast ratio of 10:1 when displaying a continuum of luminances by television, represents a severe compression of the contrast ratios which may occur in the scene (for instance, on a bright sunny day a maximum of 10,000:1 might be found) and any restrictions imposed on the already limited range of contrast that can be carried by television could be unacceptable.

To minimise flicker it is also important that the display monitor black-level is set correctly. If parts of the picture which should be black are reproduced as some intermediate shade of grey, it is possible that they will appear to flicker. Such flicker can be avoided by adjusting the monitor correctly.

Welde and Cream (1972) suggest that, although it is possible to minimise flicker in these ways, optimising the viewing conditions does not significantly reduce the flicker when a display is in the field of peripheral vision. This, together with the limiting nature of such ′optimal′ viewing conditions clearly indicates a need for reducing flicker at its source.

2.0 Reducing Flicker at Source

There are two obvious, physical ways of reducing the amount of flicker generated by a display; prolonging the phosphor persistence and increasing the field rate.

2.1 Phosphor Persistence.

An increase in phosphor persistence would reduce the amplitude of the fundamental component of the flicker by both reducing the overall amplitude and changing the waveform. Unfortunately, as phosphorescence decays exponentially it is very difficult to achieve any reduction of flicker by this means without blurring moving pictures. This may be acceptable for computer VDUs where blurring is only apparent on scrolling the screen, but for television used for remote viewing this could be a distinct disadvantage.

2.2 Increasing the Scan Rate.

The most attractive means of reducing flicker would be to increase the fundamental frequency.

a) High scan rate cameras and monitors.

Technically, it is possible to build display monitors which operate at field rates greater than 50 or 60Hz and increasingly such options are offered for computer displays.

Equally, it is possible to build high scan rate cameras with increased resolution, but these will be incompatible with existing video equipment such as video recorders and vision mixers. This is usually a serious disadvantage for closed-circuit television but seldom a problem for computer displays. The provision of suitable recording equipment is likely to be costly. In addition, the increased signal bandwidth will be a difficulty in the distribution (and if the signals are in anyway broadcast, the transmission) of the pictures from such cameras.

b) Digital Signal processing

The problems of incompatibility and increased signal bandwidth can be circumvented by converting conventional television pictures to a format with increased field and/or line rates immediately prior to display on a high scan rate monitor; thus providing a flicker-free and probably non-interlaced display of standard video signals.

Apart from simply upgrading conventional television, it is expected within the television industry, that by using similar techniques, it will be possible to minimise the transmission bandwidth used by a high definition television service and be compatible with existing picture sources and displays. Therefore, this is an active area of research and with the advent of cheap and readily available digital field storage will become a realistic proposition even for the domestic market.

The fundamental problem is how to construct the additional lines to enable a higher field rate. For parts of the picture which do not change from frame to frame the solution is easy since the same information is transmitted over and over; repeat the previous field; but where there is movement in the picture there is no such redundancy.

Many of the experimental approaches aim for a field rate of 100Hz or 120 Hz; double that of 625/50/2:1 and 525/60/2:1 respectively. If interlacing is retained then the line scan rate is doubled, while converting to a progressive scan mode quadruples the line scan rate. Unfortunately, conversion algorithms which work well for still pictures are not optimal for parts of the picture which are moving, and vice versa. It is therefore necessary to switch algorithms between or within frames when movement has been detected. Conversions which do this are said to be motion adaptive.

Essentially, algorithms which are good for still pictures combine, in some way, the information from temporally different fields, whilst algorithms good for moving pictures only use information from a single field. For example, to produce a progressive scan (i.e to scan lines 1,2,3 etc in numerical order rather than to scan them in 1,3,5.....2,4,6 order) from an interlaced scan at the same field rate it is necessary to insert additional lines into the original fields. This could be achieved either by repeating lines from the appropriate part of a previous field, or by repeating lines from the same field. The first solution would be good for still pictures and would have a better vertical resolution than the second. However the second would allow jitter-free reproduction of moving pictures.

The following are some examples of proposed conversions; the list is by no means exhaustive.

i) The Sony approach.

For 625/50/2:1 Sony have investigated conversion to 625/100/2:1 (Okada, Hongu, Tanaka 1985). Interlace is retained and the field rate is 100Hz, each field containing the normal number of lines (312.5). The additional fields are obtained simply by repetition.

If:-

A1 A2 B1 B2 C1 C2 D1 D2...........

represents the 625/50/2:1 field sequence where A,B,C...are the frames and 1,2 are the odd and even fields respectively, then after conversion the sequence is:-

A1 A1 A2 A2 B1 B1 B2 B2 C1 C1 C2 C2 D1 D1 D2........

The advantages of this system are that large area flicker is eliminated, only a single field store is needed and that moving parts of the picture are only marginally disturbed, as there is no change in the temporal ordering of the fields; There is no need for motion adaption and fuzziness of moving edges is reported to be negligible. The disadvantage of the conversion is that interline flicker is unchanged at 25Hz.

Also, Sony have marketed a converter, the DSC 10, to convert 525/60/2:1 to a non-interlaced scan, with a field rate of 60Hz, using a one-line memory. Line scan rate is doubled and there are 525 lines per field. The additional lines in each field (an unconverted field has 262.5 lines) can be generated in two ways and it is possible to switch between the two. The first simply repeats the previous line and the second inserts the mean value of the two adjacent lines. However, vertical resolution is reduced, but as noted elsewhere not by as much as might be expected (i.e. halved)

ii) The Jackson and Annagarn approach

This is essentially the same as the Sony 625/100/2:1 approach except that it is motion adaptive. The resulting field sequence where a picture contains movement is exactly the same, but when no movement is detected then the field sequence becomes:-

A1 A2 A1 A2 B1 B2 B1 B2 C1 C2 C1 C2 D1 D2 D1 D2......

The advantage is that, for still parts of the picture interline flicker frequency has been doubled and the picture is largely flicker free. However it can be seen that the original temporal order of some of the fields is reversed (e.g. A1 A2 becomes A2 A1) so even small amounts of movement will be very jittery; the motion adaption must be reliable. In addition it is no longer possible to use a single field store.(Schroder, Silverberg, Wendland, Huerkamp 1985.)

iii) The Tanaka, Nishizawa method.

This carries out the conversion of 625/50/2:1 to a progressive scan mode with 100 fields/second. The result is line and large area flicker-free for still pictures and resolution is subjectively improved. However motion adaption is necessary and moving parts of the picture show line and large area flicker. (Schroder et al 1985)

Information is taken from three pre-conversion fields to make up each new frame, which is then displayed twice. For a 625/50/2:1 field sequence:-

A1 A2 B1 B2 C1 C2 D1 D2..........

when no movement is detected in the picture, the following frame sequence is constructed:-

Aa Aa Ab Ab Ba Ba Bb Bb Ca Ca Cb Cb Da Da Db Db......

Where the frame Ba is made up from the lines of field B1 with the line-by-line average of the fields A2 and B2 inserted to complete the progressive scan. Similarly the frame Cb is made up from the lines of field C2 plus the average of fields C1 and D1. Thus a complete frame is made up from three fields.

When motion is detected in the picture the sequence becomes:-

A1´A1´A2´A2´B1´B1´B2´B2´C1´C1´C2´C2´D1´D1´D2´D2´.....

Here A1´ is generated entirely from the field A1; the additional lines are interpolated from their neighbours within the field by averaging.

When motion detection fails the effect is of picture blur rather than jitter but the system is complex and at least 4 field stores are needed.

iv) The Wendland Way

This is similar to the above in that it produces a progressive scan at 100 frames/sec, with the advantage of being completely flicker free in the still mode, but here the frames are generated simply by combining odd and even fields. (Schroder et al 1985)

The sequence:-

A1 A2 B1 B2 C1 C2 D1 D2........

becomes:-

Z Z Y Y X X W W V V U U T T S S......

where Y is all the lines of fields A1 and A2, X all the lines of fields A2 and B1, W of B1 and B2 etc.

When movement is detected the sequence is exactly the same as iii). The advantage is simplicity, but against this is a reduced tolerance to failure of movement detection. Switching of the conversion mode has to take place for smaller amounts of picture movement.

v) BBC Research Department Experiments.

Using two basic algorithms, one for still pictures and one for motion, a number of standards conversions have been tried, ranging from 625/50/1:1 to 1250/100/4:1 and 1250/100/2:1 (Roberts 1983).

The still algorithm was basically the same as the Jackson method when interlace was retained and the same as the Wendland method for non-interlaced scans. For moving pictures the algorithm was the same as the moving picture part of the Tanaka et al. algorithm. The conversion to 1250/100/2:1 was simply a version of 625/50/1:1 with a 50Hz, one line vertical perturbation and twice the line scan frequency. 1250/100/4:1 was similarly related to 625/50/2:1.

As expected, the conversions which involve a quadrupling of the line rate (ie 1250/100/2:1 and 625/100/1:1) give the best results in terms of reduction of large area flicker, inter-line flicker and line crawl. The 4:1 interlace structures do not perform very well as it is difficult to achieve a stable 4:1 interlace.

All the conversions resulting in a 100Hz field rate lead to considerable reduction in large area flicker, but vary in their reduction of interline flicker. Only an algorithm equivalent to the Sony method did not need to be motion adaptive.

vi) Motion detection.

Although motion adaptive conversion techniques potentially offer the most improvement in picture quality, one of the problems is signal noise. Being random in nature, the noise changes from field to field and so may look like motion to a sensitive detector. However, since random noise is likely to change much more frequently, from pixel to pixel, from line to line, and from field to field, than real movement, averaging horizontally, vertically and over several fields will give a degree of immunity to noise. The penalty is complexity and the amount of processing to be done in a finite amount of time.

So far, the results of using motion adaptive conversion are not entirely successful for real television pictures. (Roberts 1985)

2.3 Other Scan Structures

For a linear scanning system it is possible to broaden each line without reducing horizontal resolution in the way that simply enlarging the spot size would by adding a small, high frequency (for example 200 times line frequency) vertical oscillation to the scan raster. Such ´Spot Wobble´ techniques are not new, but given that picture quality is subjectively diminished by the visibility of interline flicker (White 1978), hiding the line structure in this way may improve the appearance of interlaced pictures.

Scanning schemes other than linear scanning have been suggested to reduce flicker for a given frame rate. One such scheme would display an image made up from a mosaic of a large number of dots, like a newspaper photograph, which would be illuminated in a pseudo-random sequence (Deutsch 1971). The display would not so much flicker as scintillate. Whilst such displays have been built, their main application has been in television systems for low bandwidth operation where bandwidth is conserved by sacrificing picture repetition rate rather than the number of elements in each picture; temporal rather than spatial resolution has been compromised. Problems lie in the complexity of synchronising the picture source with the display, and with maintaining a scan stable enough to achieve reasonable spatial resolution.

3.0 Adverse Effects of Flicker.

Although there is much reported study of the use of VDUs, the incidence of visual impairment and the occurrence of fatigue, the case for a causal link is not proven. Even less concrete is the putative isolation of flicker as the prime suspect. However there is some evidence to suggest that flicker has a detrimental effect on eye movements, and given that moderate levels of flicker are unpleasant to work with, it is not unreasonable to speculate on such a connection. It is assumed that the following also applies to the use of television for a visually demanding task, but probably not to domestic television watching.

3.1 CRTs, Fatigue and Visual Impairment.

Visual fatigue can mean a lot of things:-Subjective variables such as "eyestrain", blurred vision, headaches, eye pains etc; or objective variables such as deterioration of performance with time on a task; or changes in psychophysically measurable aspects such as spatial contrast sensitivity, or flicker sensitivity. Study methods can be experimental, etiological, or can correlate questionnaire results with the use of VDUs; but to generalise, the incriminating evidence is equivocal.

a) Experimental evidence

An experiment by Gould and Grischkowsky (1984) measured the performance, feelings (16 point questionnaire) and vision of 24 subjects, at 1 hourly intervals during a 6 hour day of proofreading from either a VDU or hard copy. The visual measures were far and near acuity, phoria, flicker sensitivity and contrast sensitivity. The results show that subjects experience some fatigue during the day, but there is no significant difference between reading from a VDU or a piece of paper. The experiment was designed so that the two display conditions were as similar as possible and subjects acted as their own controls by doing the experiment under both conditions. Gould and Grischkowsky contend, that any additional fatigue caused by the use of VDUs is in fact due to the type of work done, rather than VDU use per se; this appears to be supported; when the task is equivalent the fatigue is the same.

Exactly the opposite conclusion was reached by the authors of a similar study, Mourant, Lakshmanan and Chantadisai (1981). Here the task was a visual search task. Fatigue was measured by the times taken for subjects to move their eyes from a near point, the task sheet, to a far point, a TV monitor 6m away, read a five digit number and re-focus on the task. The experiment was run in three hour sessions and there was evidence of significant fatigue when the task was VDU based, but not when the task was on hard copy. This result is not exactly comparable with the above experiment, as fewer and different measures of visual fatigue have been used.

b) An etiological approach

Subjects in the Dutch telephone inquiries service were studied before, just after and two years after the introduction of VDUs. (de Groot and Kamphuis 1983). On the whole no change in the number or severity of eyestrain complaints was evident, and no changes in acuity or accommodation were found which could not be accounted for by aging or by a change of glasses to suit the new working conditions. However CFF measured just after, was higher than immediately prior to the introduction of VDUs. Two years later CFF had declined, the authors suppose due to the process of aging, to a value close to that before VDUs. It was not found that the increase in CFF was correlated with any increase in complaints of eyestrain.

c) Correlation and Causality

Laubli, Hunting and Grandjean (1980), surveyed the visual complaints of 4 groups of office workers in relation to their working conditions. Amongst other things, they measured the Uniformity Factor (UF) of the VDUs which their respondants were using. UF was defined simply as the lowest divided by the highest screen luminance measured during one field and integrated over an area of about 1sq mm of displayed text. Note that this is a fairly poor objective measure as it takes no account of waveform or frequency.

Laubli et al. found a significant correlation between workers who operated VDUs with low Uniformity Factors and the incidence of reduced visual acuity. These unfortunates were also found to be more likely to complain of red eyes, of shooting and burning pains and to use eye-drops more frequently than operators of high uniformity factor VDUs.

However a correlation does not indicate causality. In this case the users themselves set the controls on their VDUs, and, for a given display, it appears that one of the main determinates of uniformity factor is display contrast. It is therefore plausible that some of the workers, already suffering from poor acuity, had increased the contrast (and hence decreased UF) in an attempt to make their display more legible. The direction of causality is not necessarily from low UF to low acuity; From a single survey it is impossible to tell.

3.2 Flicker and Visual Performance.

It is frequently found that the reading of text is 10% to 30% slower from a VDU than from a piece of paper (Gould and Grischkowsky) and that blink rate is often higher (Mourant, Lakshmanan and Chantadisai) than when reading from hard-copy.

Mousaoui and Frievalds (1986) have compared eye movement patterns of subjects reading from a CRT or from paper. They found that there are significant differences, principally in the frequency and duration of fixation. Fixation pauses where the eye is held steady, and information is captured, occur more frequently, and fixations with a duration greater than 360msec are more common using CRTs. Mousaoui and Frievalds suggest that the difference, which is found even for short texts, and therefore has little to do with fatigue, is largely due to the difficulty the eye has in accommodating when there is a relative lack of high spatial frequencies in the CRT display.

However, even when care is taken to ensure that the paper and VDU displays are very similar, a difference in reading speed is still sometimes found. Further possible explanation is provided by Wilkins (1986) in an experiment which measured the size of saccadic eye movements across text, firstly when the text was displayed on a CRT and secondly when illuminated by fluorescent light. The subjects were not asked to read the text but simply to transfer their point of fixation from one specified letter to another. In both cases there was a significant interaction between frequency of illumination and the size of high velocity saccadic eye movements. For the CRT, at two field rates, 50 and 100 Hz (with no interlace) the eyes overshot their target, allowing for the normal transient saccadic overshoot, but by a significantly larger amount for the 50Hz field rate. The overshoot for the 50Hz rate corresponds to about the size of one of the letters which made up the text. Under fluorescent lighting the same sort of overshoot was apparent when the driving frequency was 100Hz, but when the flicker frequency was 20kHz an undershoot of about the same size was found.

Whilst it is quite normal for the eye to undershoot a target, the overshoots are unusual and need to be explained. It is also of interest that the effect is concrete even when no flicker is perceived and that subjects, when asked, preferred the 100Hz to the 50Hz CRT display, but mostly were unable to say why.

It is possible to record electrical signals from electrodes attached to the scalp which are phase locked to the flickering of an intermittent stimulus. In a situation similar to television viewing, Tyler (1981) recorded such evoked potentials at frequencies of up to 80Hz even though the test field appeared completely steady at about 50Hz. Further, Brindley (1962) has shown that the beat between electrical and visual stimulation of the retina can be perceived at stimulating frequencies up to 120 Hz, where either form of stimulation alone would not produce the sensation of flicker.

It therefore would appear that the visual system can respond to intermittent illumination even when flicker is not perceived. The implication is that critical flicker fusion may no longer be an adequate criterion for optimising field rate and that the intermittancy of illumination does have an adverse effect on visual performance.

However an experiment by the authors (Scheiwiller, Reading, Dumbreck and Abel 1988) failed to find any large differences in the times taken by subjects to perform a visual search task at various field rates. The task was to count the number of small circular ´targets´ hidden in a background pattern of random noise. Field rates of 50,80 and 100Hz were used, non-interlaced, and the viewing conditions were such that flicker was not noticeable in the pictures even at 50Hz. Two display monitors were used; one for 50Hz and 80Hz, the other for 50 and 100Hz, thus there were two 50Hz conditions. Figures 5 and 6 show the mean time taken to count the targets vs. the number of targets presented.

The error rate was constant across the field rates and there was no statistically significant difference in time taken between 50 and 80 Hz. At 100Hz subjects performed slightly slower than at 50Hz and the difference was statistically significant. However this difference is smaller than the difference between the two 50Hz conditions and probably explained by a practice effect not anticipated in the experimental design, and therefore of little practical importance.

The search task in the above was not suited to a square search strategy and eye movements are likely to have been less orderly than those found in reading; perhaps the interaction between display intermittency and visual performance is strong only when the pattern of eye movement is highly ordered.

4.0 Conclusions

For a typical CRT display, with a field rate in the region of 50 to 75Hz, flicker will be visible under some viewing conditions; the likelihood that flicker will be perceived can be minimised by optimising the viewing conditions.

This can be done by making the ambient lighting subdued, but it must be bright enough to be able to carry out any concurrent work, for example paperwork; and by keeping the display brightness and contrast as low as possible, consistent with the display being able to fulfill its intended purpose efficiently. The display black-level should be correctly set and the viewing distance should be such that the screen subtends about 20 degrees of visual angle.

However such conditions are very restrictive, large bright screens are to be preferred. If it is unavoidable that a display will always be in peripheral vision, for example where several displays are used at once, or the display is part of a bank of TV monitors then it is unlikely that even such viewing conditions will eliminate flicker.

Interlace will be most disturbing at close viewing distances. If a fixed viewing distance, from which the picture line structure is invisible, cannot be guaranteed then interlace is probably best avoided.

Flicker can be reduced by increasing the persistence of the phosphor, but this will only be effective when the increase is relatively large and blurring of moving pictures will occur.

Digital scan conversion of conventional TV signals to a format with a higher field rate and without interlace, immediately prior to display would appear to be the best way of reducing flicker for TV applications. It has the advantage over systems which use a high scan rate throughout that conventional and compatible equipment can be used for the rest of the system. It is probable that such processing will become widely available, even for domestic TV receivers within the next few years. However to be really effective the conversion has to be motion adaptive, and at present reliable motion detection is fairly difficult. Possibly, the advantages of up-conversion will be slightly marred by artifacts created when motion detection fails. When the equipment becomes commercially available (for the moment it is still experimental) this potential, and the possible advantages of simply de-interlacing the picture should be evaluated more fully.

There is evidence to suggest that the human visual system responds to intermittent illumination at frequencies above flicker fusion, and that flicker might have an adverse effect on visual performance even at high frequencies. This implies that flicker fusion may not always be a good enough criterion for deciding the field rate and viewing conditions. Whether or not flicker has any effect on visual fatigue or, in the long term, on health is not conclusively decided.

However, an experiment by the authors failed to find any major interaction between display field rate and an observers performance of an unstructured visual search task. This is not consistent with other findings, in particular those of Wilkins where there was a relationship between saccade size and display field rate. Perhaps the interaction is strong only where regular, predictable eye movements are involved, as in reading and that any detrimental effects of flicker are task dependent.

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Modulation Amplitude of Fundamental Sinusoidal Component vs CFF

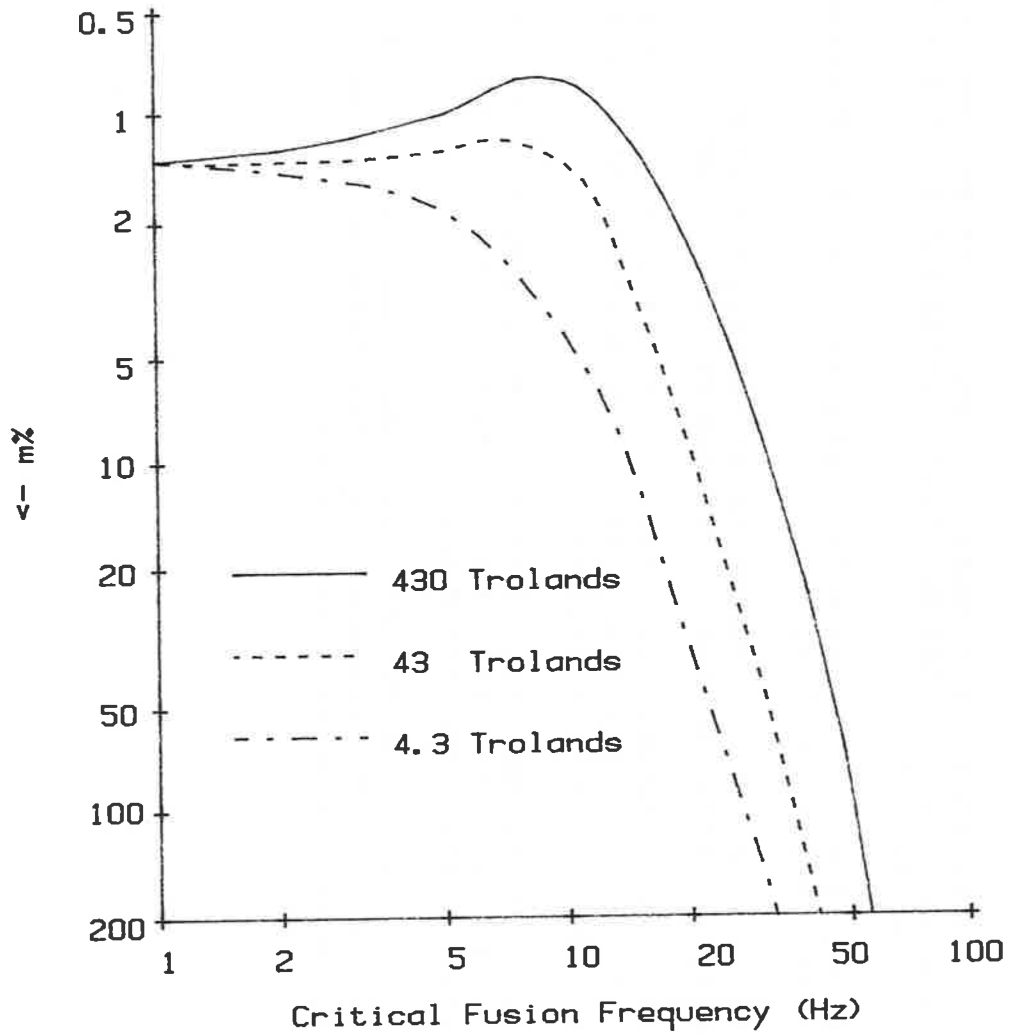


Figure 1.
(Data from de Lange 1958)

CFF vs. Log Retinal Illuminance.

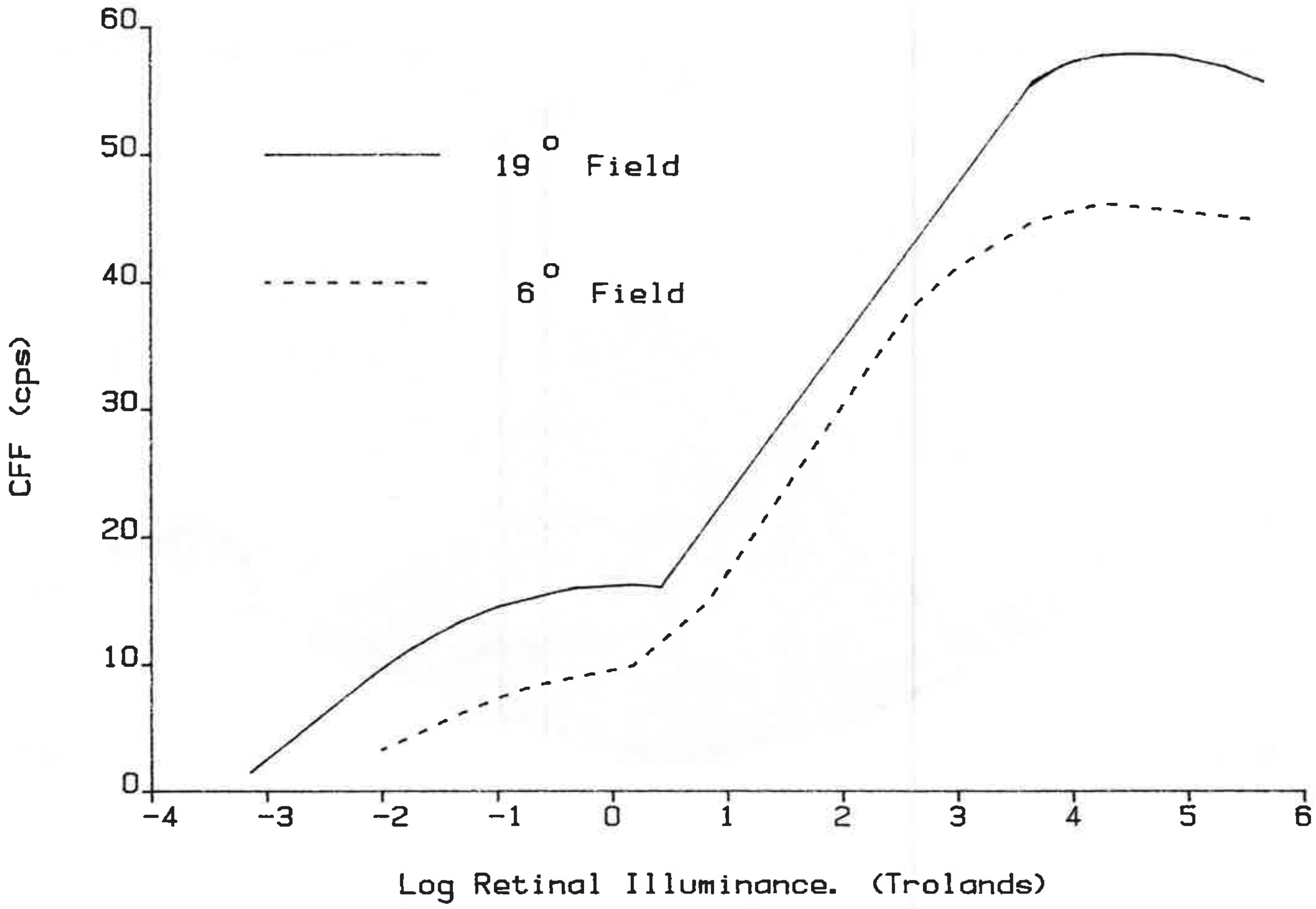


Figure 2.
(Data from Hecht and Smith 1936.)

Modulation Sensitivity as a Function of Spatial and Temporal Frequency.

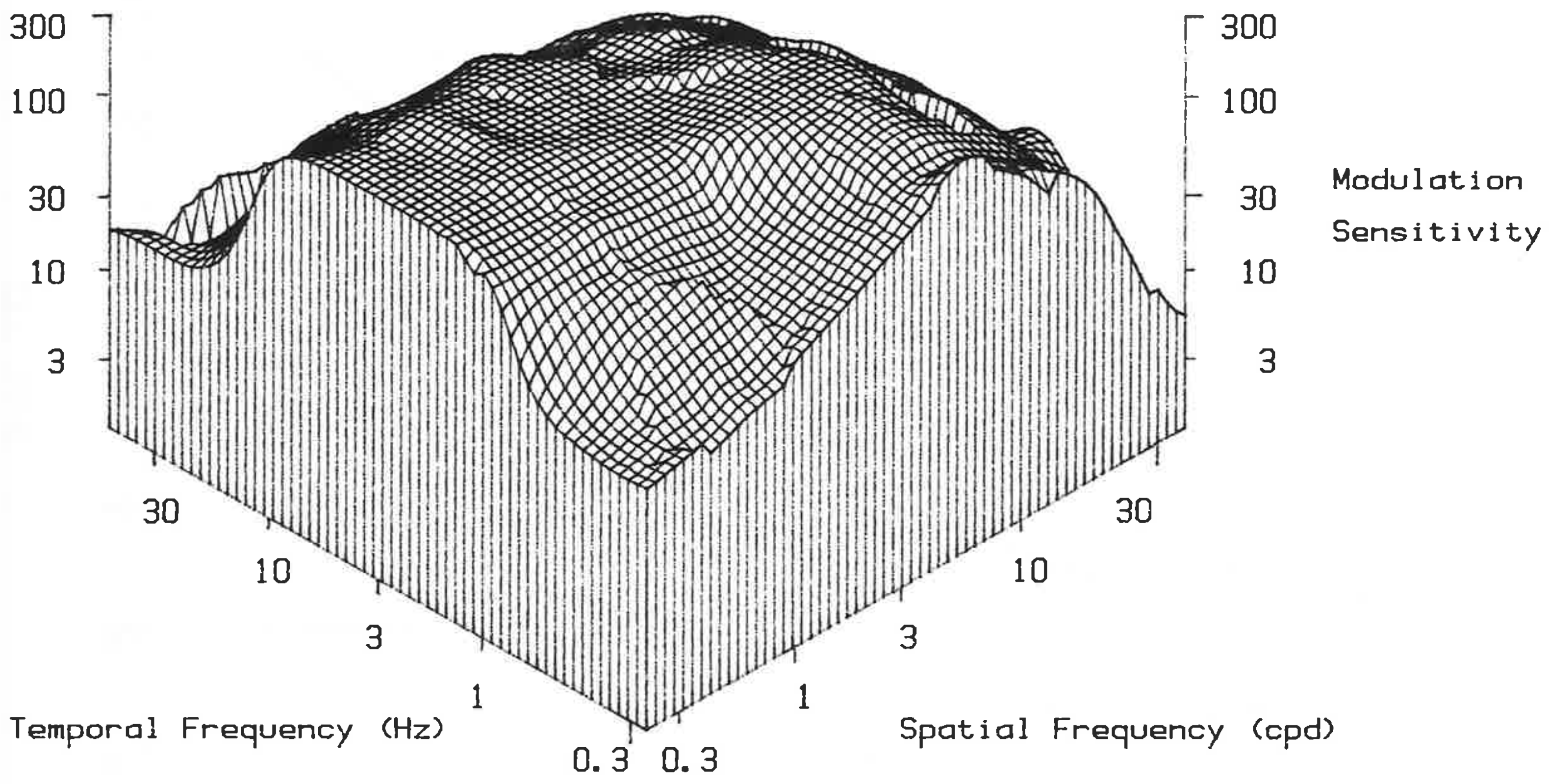


Figure 3.

Plotted with Data from Robson (1966)

Flicker Assessment for an Older Technology Monochrome Monitor.

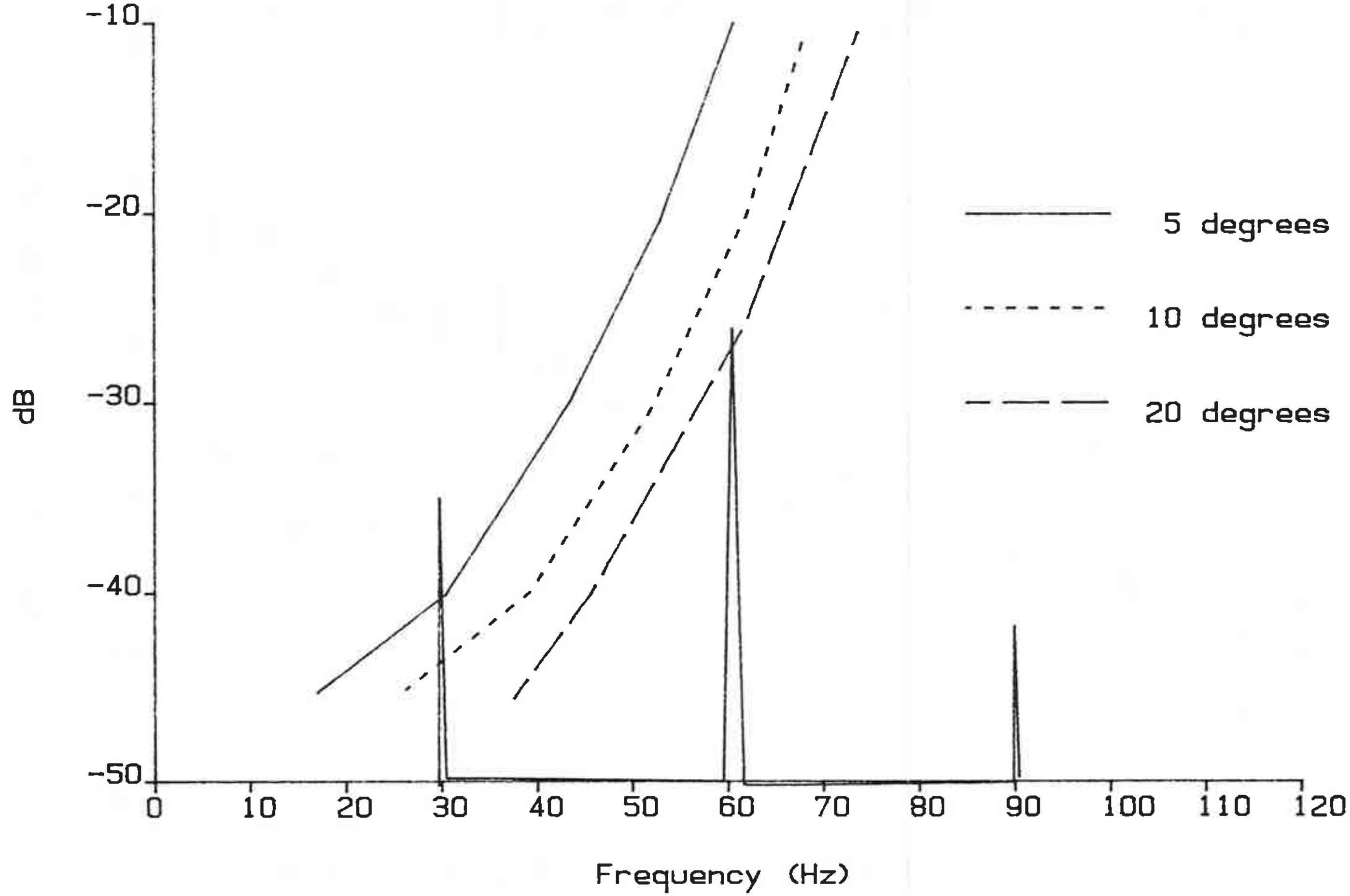


Figure 4.

Typical Flicker Assessment Plot from Chaplin and Freemantle (1987).

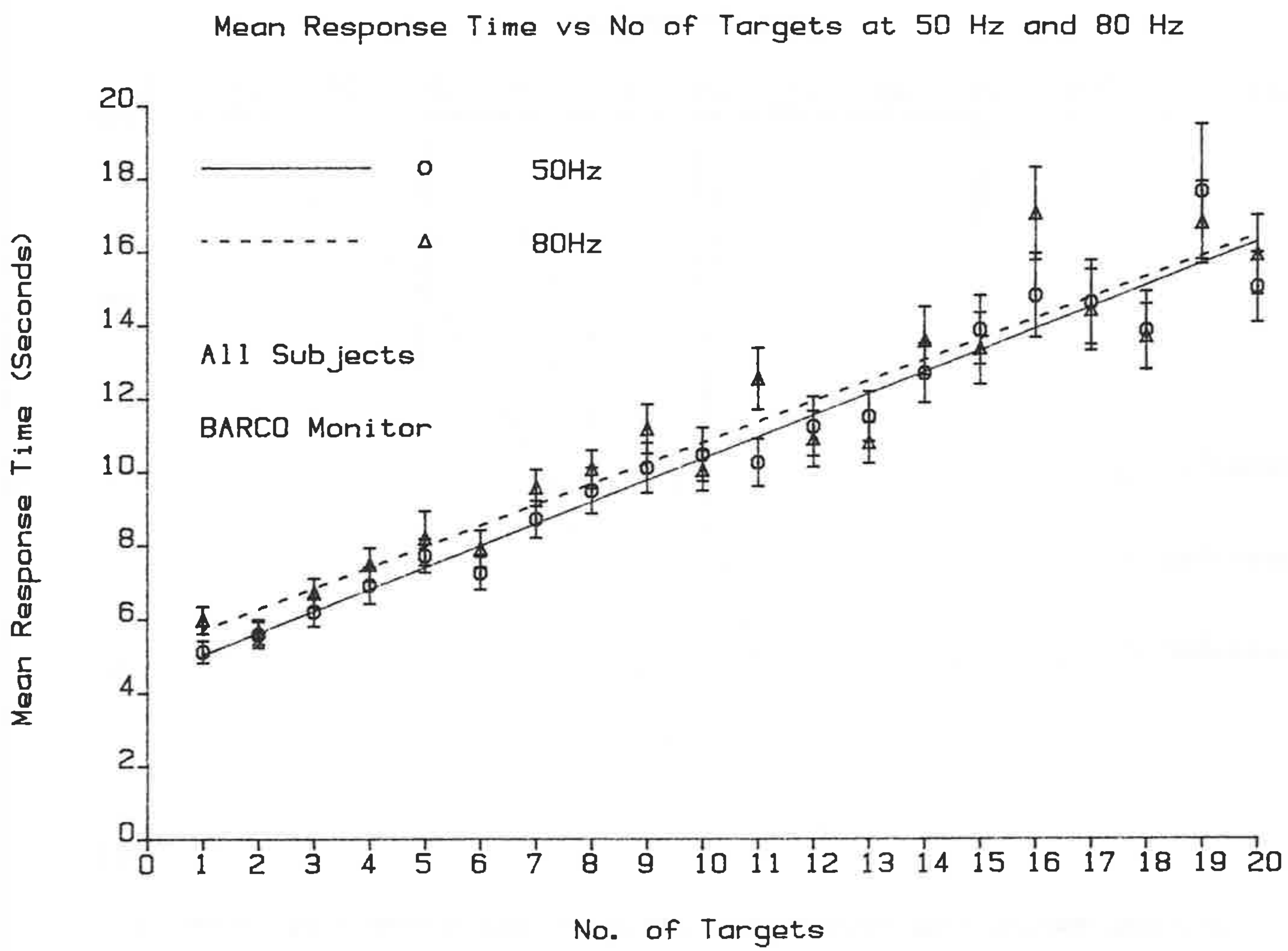
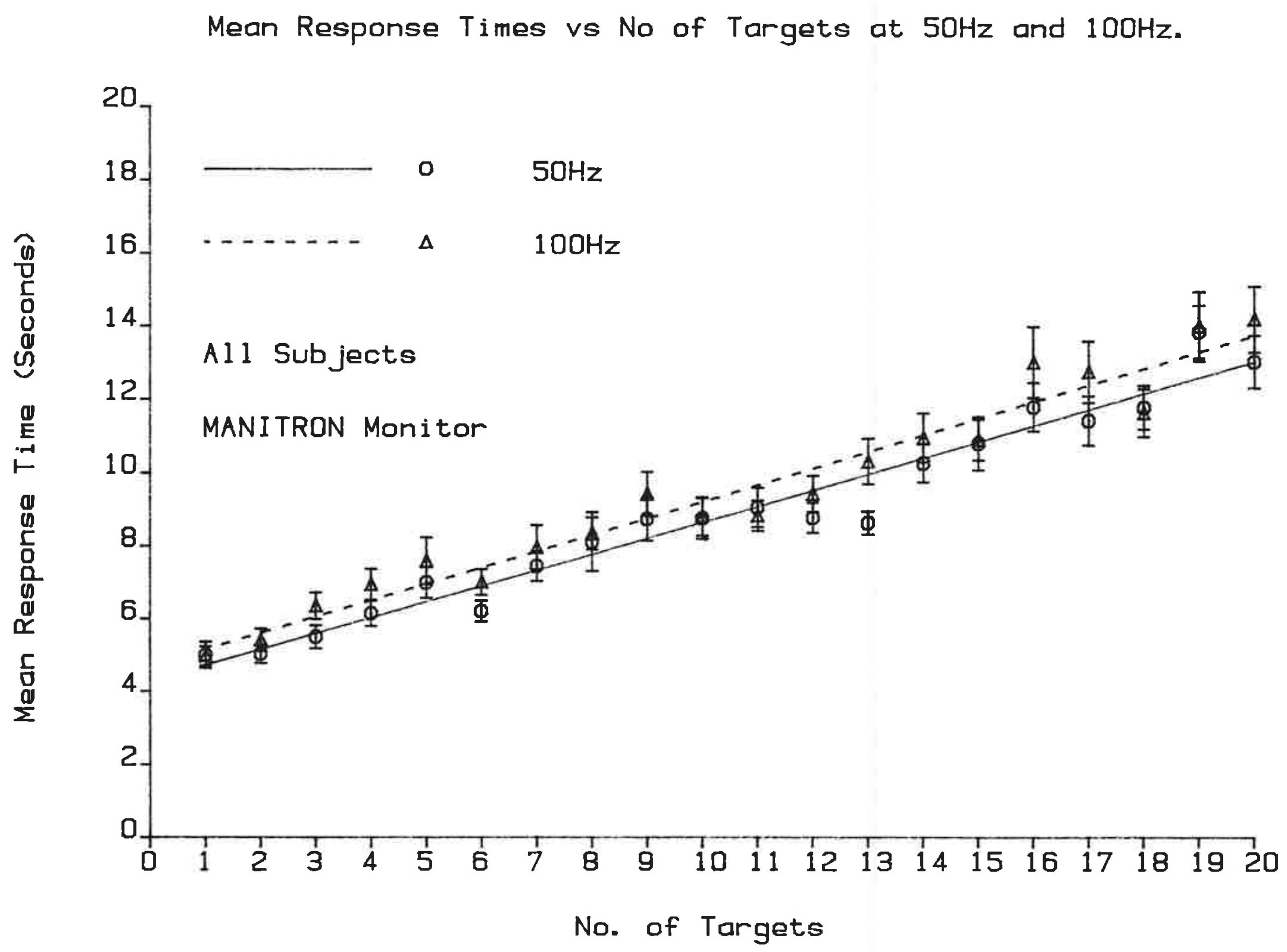

Mean Response Time vs No of Targets at 50 Hz and 80 Hz
Mean Response Time (Seconds)
0
2
4
6
8
10
12
14
16
18
20
50Hz
80Hz
All Subjects
BARCO Monitor
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
No. of Targets

Figure 5.



Mean Response Times vs No of Targets at 50Hz and 100Hz.
50Hz
100Hz
All Subjects
MANITRON Monitor
Mean Response Time (Seconds)
No. of Targets
0
2
4
6
8
10
12
14
16
18
20
0
1
2
3
4
5
6
7
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Figure 6.