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Computer-based analysis and restoration of Baird 30-line television recordings

The first electrically recorded television pictures were made by J L Baird in the late 1920s. They are so poor in quality that they have so far defied attempts to replay them. Through the use of digital image processing techniques, the pictures can now be shown. Those same techniques reveal previously unknown details about the experimental apparatus used to record these pictures. This direct evidence allows the reader to make some assessment of the contribution by Baird to the history of television.

In the late 1920s, one of the world's first practical television systems went 'on the air' in Britain. The system was developed by John Logie Baird who, in 1926, gave what is considered to be the first demonstration of 'true' television. Crude by modern standards, the system used only 30 lines to build up each picture. The pictures were scanned mechanically in both the studio and the domestic 'Televisor' receivers. Transmissions continued until the mid-1930s when developments in fully-electronic television led to the demise of the 30-line service. It was replaced with the world's first regular high-resolution (405 lines per picture) television service.

Baird's early experiments made him a legend in his own lifetime. His mechanical approach allowed him to try out ideas which would not be possible in the electronic systems for many years to come. In fact, colour television, stereoscopic television and television by infra-red light were all demonstrated by Baird before 1930.

Much to the frustration of the would-be researcher, precious little tangible evidence of these achievements exists today. However, Baird did leave direct proof of one of his early achievements. This takes the form of recordings of his 30-line vision signal on wax discs. As far as is known, these discs contain the first electrical recordings of television in the world.

Today only a few of these discs remain. By analysing them together with contemporary writings, the story of the progress and the problems of his video recording experiments can be uncovered.

'Phonovision'

The story appears to start in 1926 when Baird applied for a patent on an idea for recording vision and sound signals (reference 4). He called this process 'Phonovision'. Over the following twelve months he applied for more patents on the

Figure 2. Typical of the Phonovision disc labels is this one from the earliest disc so far found — 20 September 1927

subject. One in particular (reference 5) described the 'Phonovisor'. This was to be a simple machine used both for playing back and displaying pictures from the Phonovision discs. Although ingenious in its simplicity, neither it nor the discs ever appeared from Baird commercially.

In writings of the time, indications were given as to how the work was progressing:—

> 'Baird . . . has initiated many experiments in the recording of image sounds . . .'

and

> '(Phonovision) . . . is still in the laboratory stage of its existence . . .' (reference 1, 1928).

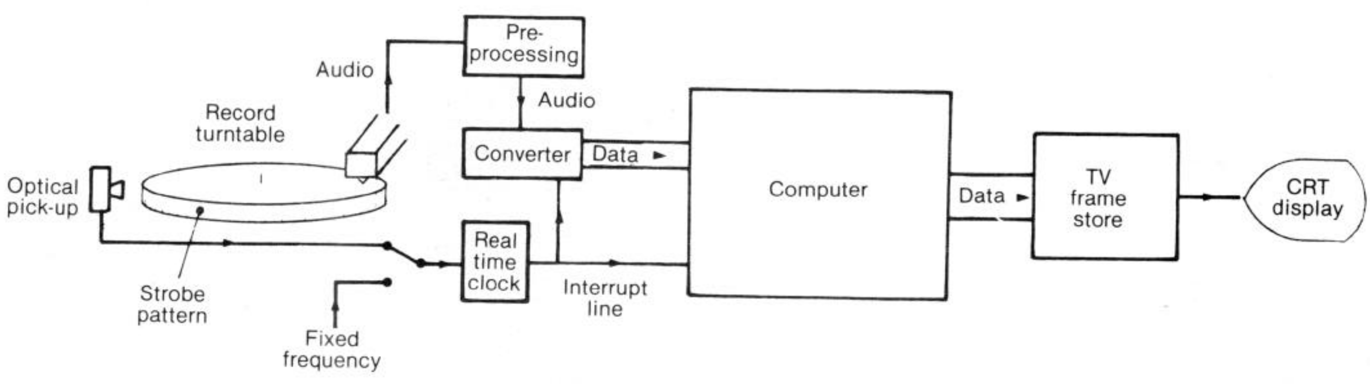


Figure 1. Diagram of computer-based image processing hardware

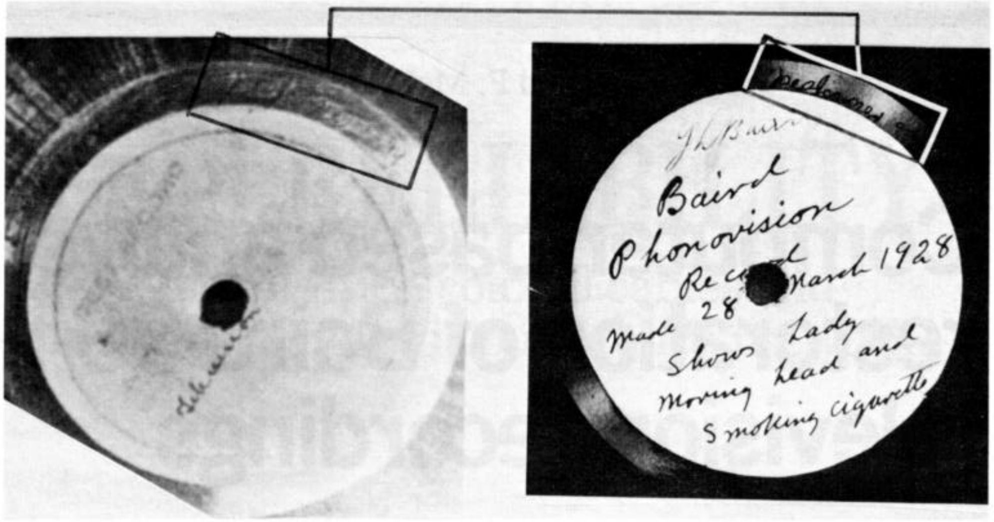


Figure 3. Handwritten label on the March 1928 disc (right) is stuck over the original 'Test Record' label. The photo on the left is an enlargement of one which appears in the July 1928 issue of Television *journal. Note the handwriting of the scratched message within the boxes — 'Miss Pounsford' — is identical in both photos*

> '. . . we have now succeeded in getting . . . images (back from disc) and we can see . . . a crude smudgy replica of the person whose image has been put on the gramophone record . . . at the present time it is more of a curiosity . . .' (reference 7, J L Baird, June 1928).

> '. . . at present, (Phonovision) is merely a scientific curiosity . . .'

and

> '. . . the Baird Company are pursuing their investigations with Phonovision so that the apparatus might be perfected . . .' (reference 2, 1931).

Phonovision dropped out of the news reports from then on. In 1934, the following extract hinted at a development period around 1928:—

> '. . . the principles and practice of (Phonovision) were established about six years ago . . .' (reference 6).

A close study of the press reports and publications of the day shows that, unlike Baird's other experiments, the reproduction of *pictures* from the Phonovision discs was never demonstrated. This indicates that Baird was never sufficiently satisfied with the picture quality to give a demonstration.

More recently, attempts have been made to get recognisable pictures from these discs (references 9, 11, 12). Only vague shapes have been observed and photographed. Crude stills from a high-quality 1935 recording of 30-line test pictures have even been reproduced (references 9 and 13). However as this recording post-dates the Phonovision discs by about eight years, it is of little historical significance.

The failure of these attempts to get anything recognisable is a result of the very poor quality of the recorded vision signal. In order to recover something like the original scene quality, it is necessary to use elaborate computer-based techniques to restore and enhance the pictures.

The image processing apparatus

Digital image processing is now a widespread engineering tool used in many walks of life. To apply image processing methods to these 30-line video recordings, the signal has to be converted into a form compatible with the computer. The converted signal is then processed to enhance or restore the pictures and the result is displayed on a conventional TV screen.

The equipment used to study these recordings is shown diagrammatically in **Figure 1.** At the heart of this home-built system is a computer based on a standard 8-bit microprocessor. A suite of programs controls the fetching, analysis and manipulation of the Phonovision pictures.

The audio signal from the Phonovision disc is pre-processed before being converted into a stream of binary numbers. Each number corresponds to the voltage level of the signal at the precise instant of the conversion. A unit called a real-time clock sets the rate at which the signal is converted and commands the computer through its interrupt line to fetch the current number from the converter. The real-time clock can be phase-locked to the rotation of the Phonovision disc via an optical pick-up or fed from a fixed frequency source.

Once fetched by the computer, the converted values are stored in the computer's data memory and transferred to a TV frame store. The frame store acts like a TV standards converter, providing a flicker-free display of the processed 30-line picture at standard 625-line rates and allowing the moving pictures to be recorded onto video-tape.*

**Some of the most interesting sequences showing movement have been featured in the Granada Television series entitled* Television.

Figure 4. Sequence from September 1927 disc showing a hand sweeping over the ventriloquist's dummy

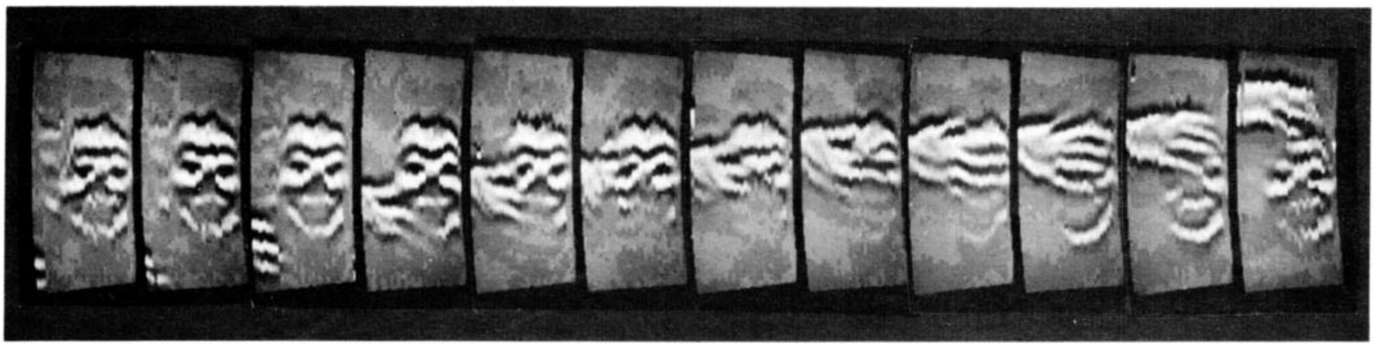


Figure 5. Sequence from September 1927 disc showing fast sideways movement of the dummy's head. This and other similar sequences show distortion caused by Nipkow disc scanning and were used to derive the aspect ratio

When sufficient numbers have been stored inside the computer, a sequence of 30-line TV pictures can be analysed and manipulated. The ability to analyse the pictures is vital to find out what types of distortion the pictures have suffered. Manipulation of the pictures allows the distortion to be suppressed.

Before delving into the details of the processing, it is worthwhile to take a close look at the discs themselves.

The discs

The Phonovision discs all show a remarkable physical similarity. This indicates that they stem from a single source. They resemble 10-inch diameter 78rpm wax audio discs. A typical label is shown in **Figure 2.** Each label is a standard 'Test Record' label from the Columbia Graphophone Company complete with date and catalogue number. This information is summarised below for four of the discs.

Catalogue Number	Date
SWT 515-4	20-Sep-1927
RWT 620-4	10-Jan-1928
RWT 620-11	10-Jan-1928
RWT 115-3	28-Mar-1928

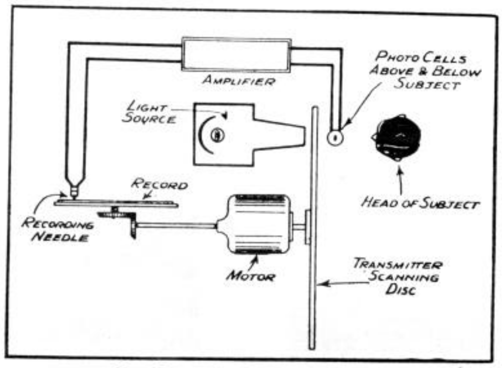
The catalogue number appears to act as a reference number to a particular recording session. Since the catalogue numbers of the two discs dated 10-Jan-1928 differ only in the last number, this may well indicate the 'take' in the recording session.

The dates on the labels are assumed to be the recording dates. This is inferred from the recognition of the 'take' number and is corroborated by the March 1928 disc. On this disc the 'Test Record' label is covered by a hand-written label **(Figure 3)** signed and dated by J L Baird. Furthermore a picture of this very disc appears in a journal published in July 1928 (reference 8).

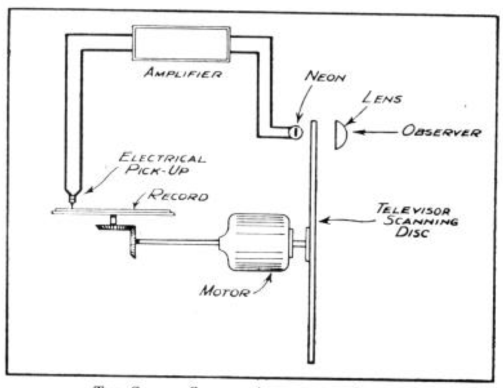
Characteristics of the recorded vision signal

Recording the 30-line video signal in the 1920s was much simpler than one might at first think. With only 30 lines per picture (or TV frame) repeated 12½ times per second, the highest frequency present was so low that it was actually audible. The video signal could therefore be transferred to disc using the audio recording techniques of the day.

One of the major drawbacks of the 30-line system was synchronisation of the receiver to the video signal. Phonovision however got round that problem in a convenient way. By driving both the scanning disc and the Phonovision recording apparatus from the same motor (through gears) and then using a similar linked arrangement for playback, synchronisation would be guaranteed. Both arrangements are shown in **Figure 6.**



How Phonovision Recording Takes Place



The Simple Scheme Adopted to Reproduce the Image Previously Made on the Record

Figure 6. Diagram of the idealised recording and reproducing arrangements for Phonovision discs from a 1931 publication (reference 2)

Early study of the video signal using the computer revealed features which are shared by

Figure 7. Sequence from March 1928 disc showing a lady's head moving to the right and left. The time taken for this sequence is only 0.8 seconds at 12½ frames per second

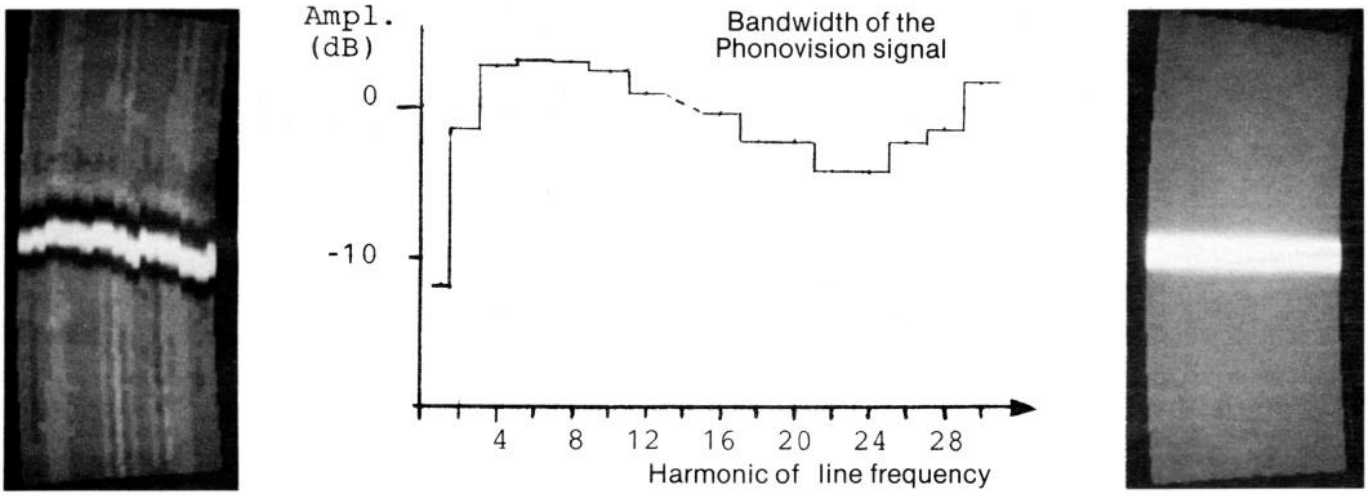


Figure 8. The power bandwidth of the entire Phonovision process is derived from a white bar test signal taken from the September 1927 disc (left, above). From its Fourier analysis, an ideal white bar is synthesised (right, above). Subtracting the power spectra of the two pictures gives the graph of system bandwidth

Figure 9. Effect of using motion-compensated temporal filtering shown on single frames from multi-frame sequences. Note the reduction of the speckles and the general 'cleaning-up' of the pictures

all the Phonovision discs. The signal is directly recorded as base-band (not modulated onto a carrier). There are 30 lines to each frame with no evidence of synchronising pulses. The frame repetition rate is 3.9 per second when the discs are replayed at 78rpm. This means that there are exactly three 30-line frames on each revolution of the Phonovision disc. To get the rate of 12½ frames per second used by Baird, the disc has to be replayed at the staggering speed of 250rpm. A consequence of this high speed is that the recordings are only 60 seconds long.

Recording speed — fast or slow?

There is a possibility that a speed slower than 250rpm was used when recording these pictures. This would of course mean a slower picture rate. Evidence for this comes from two observations: subject movement and the power spectrum of the video signal.

Replaying the pictures through the computer at 12½ frames per second shows anomalously rapid subject movement. This is exemplified in **Figure 7** where the subject's head moves from face-on to the right and then to the left, all within the space of 10 frames. At 12½ frames per second (250rpm) this movement takes only 0.8 seconds.

A distinctive feature is the absence of low video frequencies in the signal from the discs. Grey tones cannot be rendered accurately, giving an unnatural appearance to the subjects.

By relating the power spectrum of a distorted white bar that appears at the start of the September 1927 recording to an idealised white bar, the frequency bandwidth of the overall

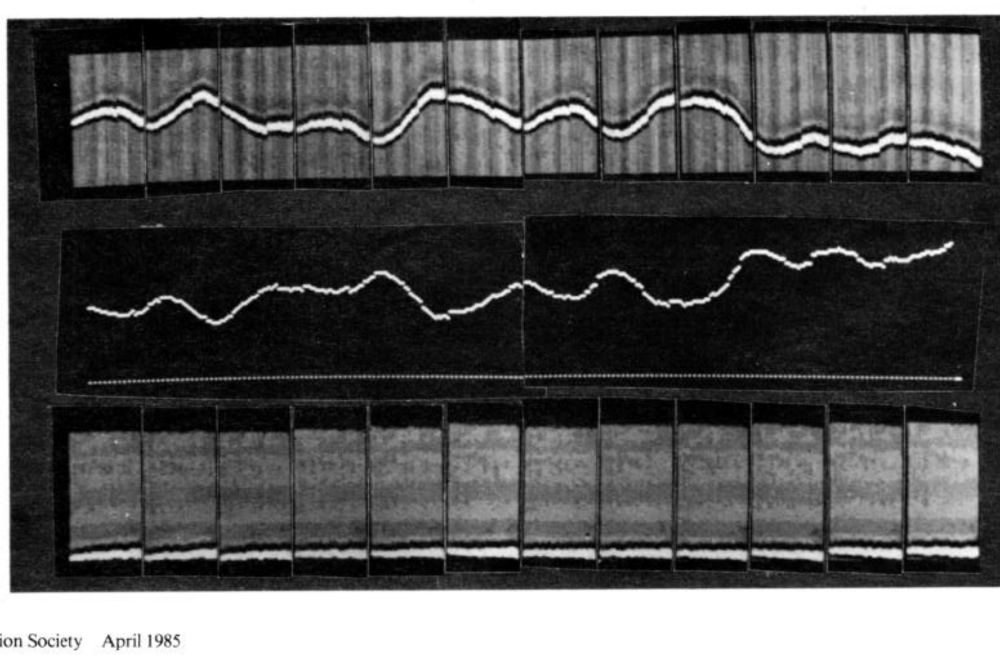


Figure 10. Sequence from September 1927 disc showing the effect of fluctuation in the replay speed (top), the computer's estimates of the effect (centre), and the result after this is removed (bottom)

system (including record and playback equalisation) can be estimated. The result is shown in **Figure 8.** The signal suffers a 3dB attenuation at approximately three times line rate and is roughly 15dB down at the line rate. At 12½ frames per second (250rpm), the line rate is 375Hz giving a 3dB high pass cut-off at about 1100Hz. This is much higher than would be expected from using the audio recording techniques of the day. It is a strong indication that the recording speed was lower than 250rpm and hence that the frame rate did not conform to the Baird 'standard' of 12½ frames per second.

Restoring Baird's images

The video signal from these discs is very poor in quality and suffers from many forms of distortion. The three main sources of distortion are:—

- Lack of low frequencies
- Surface noise (at all frequencies)
- Fluctuation in speed

The lack of low frequencies in the video signal is a problem which still defies solution. Noise from the recording itself becomes progressively more dominant with decreasing frequency until the vision signal drops irrecoverably below the noise level. Simply boosting the signal at these frequencies also boosts the noise. Consequently digital filtering (with phase correction) could only be used to eliminate noise at low frequencies and to 'flatten out' the power spectrum at mid-frequencies. This contributes to the harsh and somewhat unnatural appearance of the pictures.

Disc surface noise acts like a pattern overlying each picture. A scratch or 'click' appears as an instantaneous variation in brightness whilst noise gives a speckled appearance to the picture. These can be suppressed since the surface noise is random whilst the scene hardly changes from one frame to another. A computer-based temporal or time-domain filter (reference 17) reduces the effects of surface noise by taking the average brightness value at each point in the picture over three consecutive frames. For each point in the frame being filtered, the filter not only looks at the same point on the adjacent frames but searches around them looking for further points with a minimum variance in brightness. Having found them they are averaged to give the filtered image. This elaborate technique compensates for movement in the scene. **Figure 9** shows examples of this powerful filtering.

The most objectionable distortion is caused by an excessive fluctuation in replay speed. This affects all the early recordings. With no sync pulses to 'peg' the lines in place, the picture tears up and down the display screen in a seemingly random manner. The extent of this problem can be appreciated by studying **Figure 10.** This is a sequence of consecutive frames of a horizontal white bar taken from the earliest disc studied. The speed fluctuation causes the instantaneous position of the bar to vary rapidly.

Automatic procedures were devised to remove this fluctuation (reference 14). The computer looked for best matches between the current TV line being processed and some 'history' of the previous lines in the sequence. When the best match was found, the line was shifted back into position.

In **Figure 10** the computer's correction is plotted as a graph along with the corrected sequence. This graph reveals useful information about the recording apparatus. Close study shows an underlying periodicity over three frames.

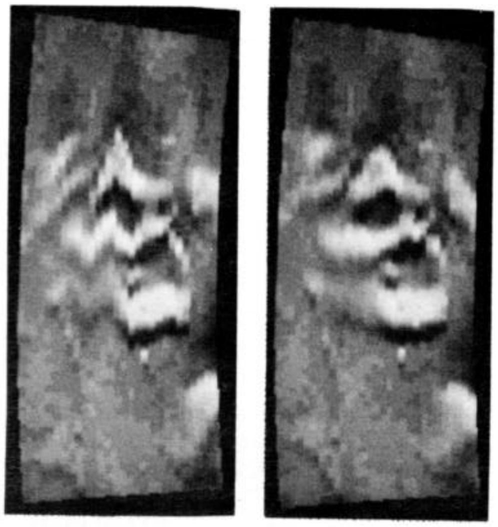
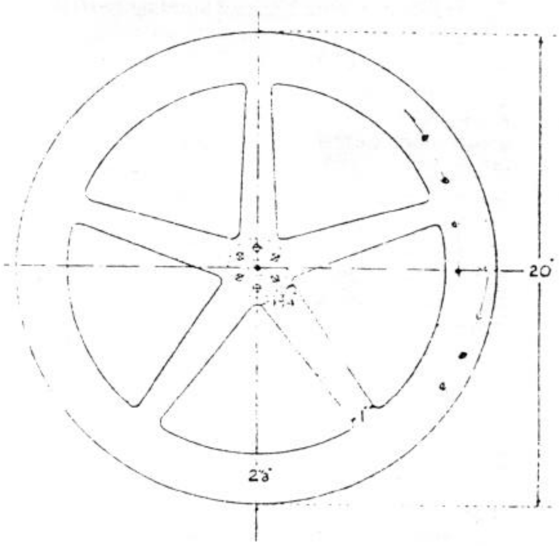


Figure 11. Automatic removal of very fast variation in the line-position in the March 1928 recording



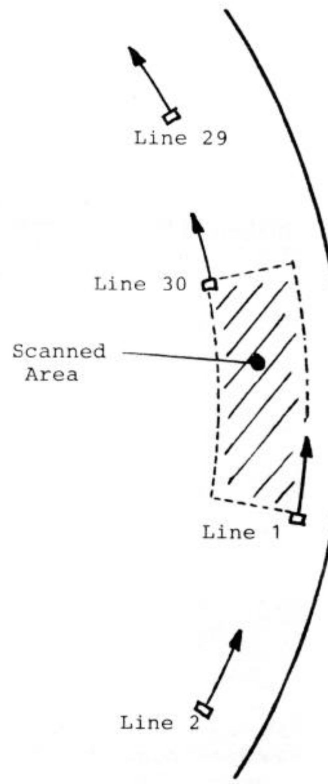


Figure 12. Pinhole (Nipkow) disc as used in the 1930s style Baird 'Televisor'. The exploded view shows that scanning covers a small area on the periphery of the Nipkow disc

Subjecting it to Fourier analysis reduces this complex graph to a list of the component frequencies. The dominant frequency is at one third of the frame rate. This is the rotational rate of the record turntable. Its second harmonic is also strong with a 180° phase shift. The third harmonic coincides with the frame rate and still higher harmonics relate to subtle and complex variations within one frame time.

Presence of a particular frequency indicates that there is a modulation of the rotational rate of the disc at that frequency. The size of the first and second harmonics of the turntable rotation speed points to mechanical resonance in the turntable assembly as being the cause. The presence of the second harmonic is a classic indication of either imbalance or misalignment. Specifically the 180° phase shift of the second harmonic indicates the following possible causes:—

- Imbalance from a bent drive-shaft.
- Parallel misalignment of linkage.
- Angular misalignment of linkage.

The speed fluctuation is at a much reduced level in the later recordings showing that progress was being made in the mechanical design. The March 1928 disc is rather different however. Plainly obvious from the pictures taken from this disc is a very fast variation in line position. Analysis shows that the variation is a result of

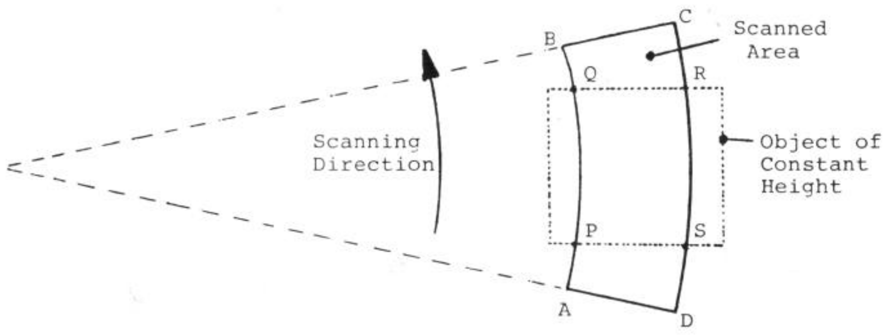


Figure 13. The aspect ratio can be calculated from measurements of an object having constant height across the scanned area

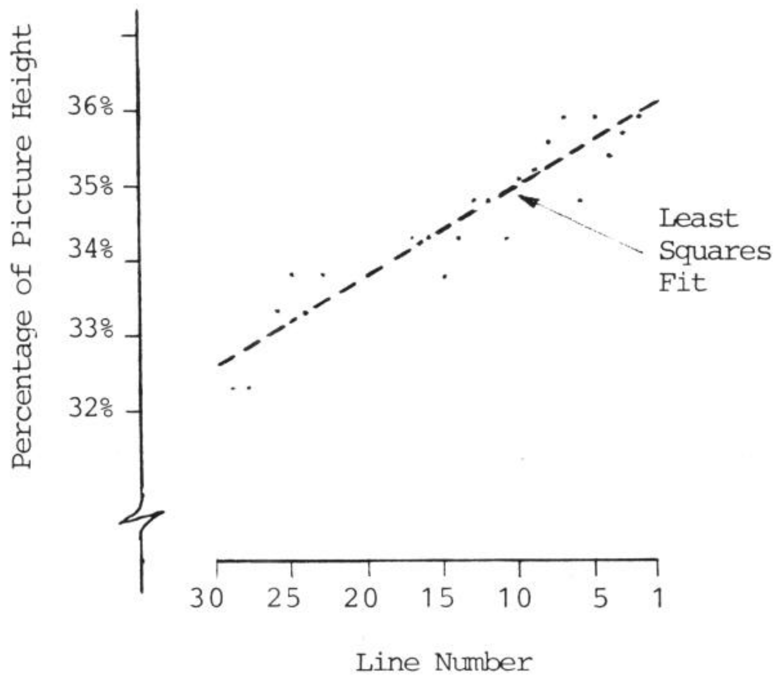
static mechanical resonance between the drive-shaft of the scanning disc and the turntable gearing assembly. The sharp triangular peaks in the distorted picture **(Figure 11)** indicate gearing backlash as a result of the resonance. The main excitation function for the resonance remains a mystery.

All the early discs show additional patterning which does not vary from one frame to the next. This is shown well on **Figure 8** and **Figure 10** (upper) on what is supposed to be a straight horizontal line. The vertical steps at lines 5 and 11 (counting from the right) are not caused by resonance but by poor workmanship in the construction of the Nipkow scanning disc. This effect is the result of not placing the 30 apertures at exactly equal angles around the periphery of the disc. For instance the step between lines 11 and 12 show a 0.4° error (3.2 per cent of line length) in positioning the corresponding apertures. Since all the early discs show this patterning the same scanning disc must have been used throughout. **Figure 18** shows examples of processed single frames after removal of the speed variation.

Views of heads

The subject matter is more interesting than might be expected from engineering test discs. The recordings consist mostly of head-and-shoulders views. The September 1927 disc starts with a horizontal white bar followed by one of Baird's ventriloquist's dummy heads (reference 15). A hand moves in to support the back of the head. After sweeping his other hand over the face **(Figure 4),** the operator moves the dummy head from side to side **(Figure 5).**

Figure 14. Graph of variation in the size of the dummy's head as a function of the line number (from Figure 5)



The first of the January 1928 discs is very poor in picture quality. The lighting arrangement for all the recordings is demonstrated well on this disc. As the head moves towards the 'camera', the subject appears to move from total darkness into a pool of strong light.

Showing none of the faults of its partner, the second January 1928 disc shows quite agile head movement of the same subject. Detail is so good that even the eyes can be seen to open and close.

The name 'Miss Pounsford' appeared scratched on the surface of the March 1928 disc. This (so the label reads) 'shows lady moving head and smoking cigarette' (**Figure 3** and reference 16). Close study shows no evidence of her smoking but facial expressions and head movement are very apparent. Throughout the recording she appears to be talking and generally enjoying herself.

Scanning the scene — the Nipkow disc

The Nipkow disc for the Baird system had 30 apertures arranged at precisely equal angles around the periphery of the disc. Each aperture corresponded to one of the lines making up the picture and one full revolution of the Nipkow disc gave one complete picture. **Figure 12** illustrates the arrangement for the pinhole version of the disc used in the 1930 domestic 'Televisor' receivers. As one aperture completes the traverse of the small viewing area on the edge of the disc, the next aperture enters from the bottom. Each aperture was placed slightly closer to the centre of the disc than the previous one. This allowed the whole of the area to be swept by one revolution of the scanning disc. The resultant picture was characteristically curved as each line was a section of arc. As this scanning path matched up exactly with the 'camera' in the studio, no distortion of the picture was observed.

If the Phonovision recordings were made with a Nipkow disc, the distortion caused by arc-scanning should appear. This effect is purely geometric and almost insignificant when compared with the other distortions but it is capable of being measured precisely with the aid of a computer.

In the following calculations, the subject being viewed by the Nipkow disc is assumed to be constant in height across the scanned area ABCD in **Figure 13.** AB and DC are the inner and outer lines scanning the scene vertically from bottom to top. In the Baird 'standard', line 1, the first line in each picture, is DC. Scanning across the picture is from DC to AB.

From the Figure it can be seen that, although PQ = RS (same height), the fraction PQ/AB is greater than SR/DC. The computer takes samples of the Phonovision signal at a constant rate giving a fixed number of samples per line. The object will therefore appear to be 'taller' (more samples in height) on the line nearest the centre of disc rotation, AB, than on lines further out.

By luck more than anything else, one of the recordings can be used to measure this distortion. This is the earliest disc of those studied and shows a ventriloquist's dummy head which, for part of the recording, is moved from side-to-side **(Figure 5).** If a Nipkow disc were used to scan the head, a change in its vertical size would be expected as it moved from one side to the other.

Accurate measurements were made of the distance from the bottom of the 'forehead' to the top of the 'chin' on the line passing through the centre of the 'nose'. This was measured for as many sideways positions of the dummy head as could be used reliably over a short sequence. The measurements have been plotted on a graph **(Figure 14)** along with the 'best-fit' to the measurements calculated from a least-squares approximation. From this 'best-fit', the divergence, which is characteristic of Nipkow disc scanning, can be seen. The total variation is small — the object being about 9 per cent 'taller' on line 1 than on line 30. The surprising fact is that because the object is 'taller' on line 1 this line must be the innermost and line 30 the outermost on the scanning disc. This is the opposite of that expected from the Baird 'standard' of 1929 onwards and the opposite of that measured by the author on the high quality 1935 'Major Radiovision' disc recording (reference 14 for pictures) but it agrees with pictures from the period 1927-1928 (see reference 2, page 56). The actual value of this divergence is important because it permits the calculation of the aspect ratio.

Calculating the aspect ratio

Assuming that the subject does not change in height across the scanned area, the aspect ratio of the area can be calculated from the equation given below. All that is needed is the size of the object at line 1 and line 30 expressed as fractions of the length of the TV line. These fractions can be taken directly from the graph in **Figure 14.** The only other assumption is that the Nipkow disc scans one picture per revolution.

Aspect Ratio, $AR = -\pi \cdot ((1 + a)/(1 - a))/30$

where $a = \sin x / \sin y$

and x,y are respectively the angles of arc PQ, SR in Figure 13 — the fractions of arc the object occupies at lines 1 and 30 respectively

From the graph in Figure 14, the dummy's head occupies 0.357 of the length of line 1 and 0.326 of the length of line 30. This gives 'a' = 1.0949 and the corresponding aspect ratio, AR = 2.311.

This value is very close to the Baird 'standard' of 2.333 (7 units vertically to 3 units horizontally) and confirms that the Nipkow disc did indeed scan one 30-line picture per revolution.

How the pictures were recorded

Photographs showing the Phonovision equipment **(Figures 15, 16)** first appeared in publications in the middle of 1928 (references 7, 8) These show a record turntable apparently linked to the drive shaft of the (obscured) scanning disc. When studied in conjunction with the recordings themselves, it appears that the recordings were made either on this or similar apparatus. Of the disc-cutting apparatus (reference 10) little is known. It does not appear in any contemporary photographs. However its performance has been measured to be similar to professional studio quality for that time.

Helical gearing beneath the turntable **(Figure 16)** transfers the rotation of the horizontal drive shaft (disappearing into the wall) to the turntable. Measuring the relative diameters of both parts of the gear assembly from the photographs gives a ratio of 3:1 approximately. For three rotations of the drive shaft, the turntable completes one rotation. If the drive shaft were connected directly to a scanning disc which scanned one frame on each rotation, then there would be three 30-line frames on each rotation of the record turntable. This agrees *exactly* with observations made from the vision signal.

Furthermore, by following the direction of

Figure 15. General view of the Phonovision equipment. The pick-up arm is for replaying. The disc cutter is not shown. Note the dummy head to the left of the turntable

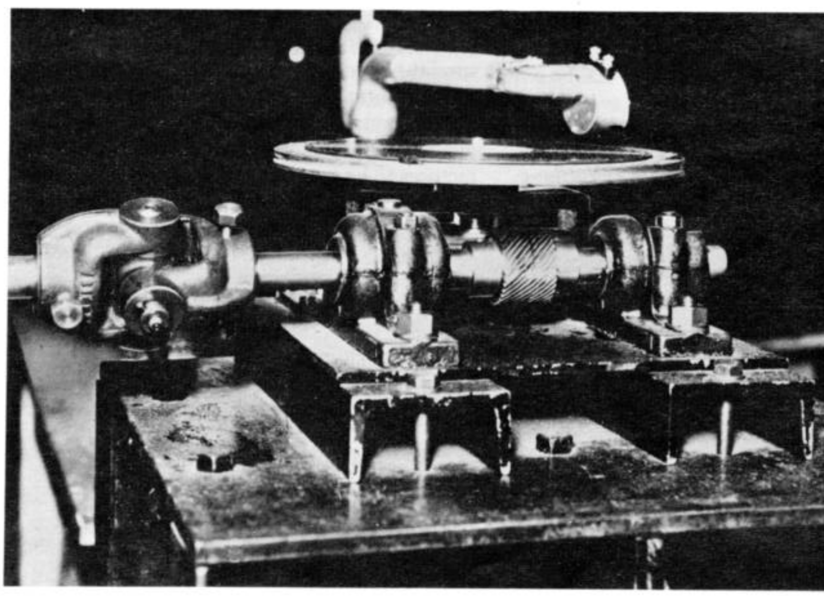


Figure 16. Detailed view of the helical gear assembly underneath the turntable of Figure 15. End bearings and a universal joint on the main drive shaft can be seen

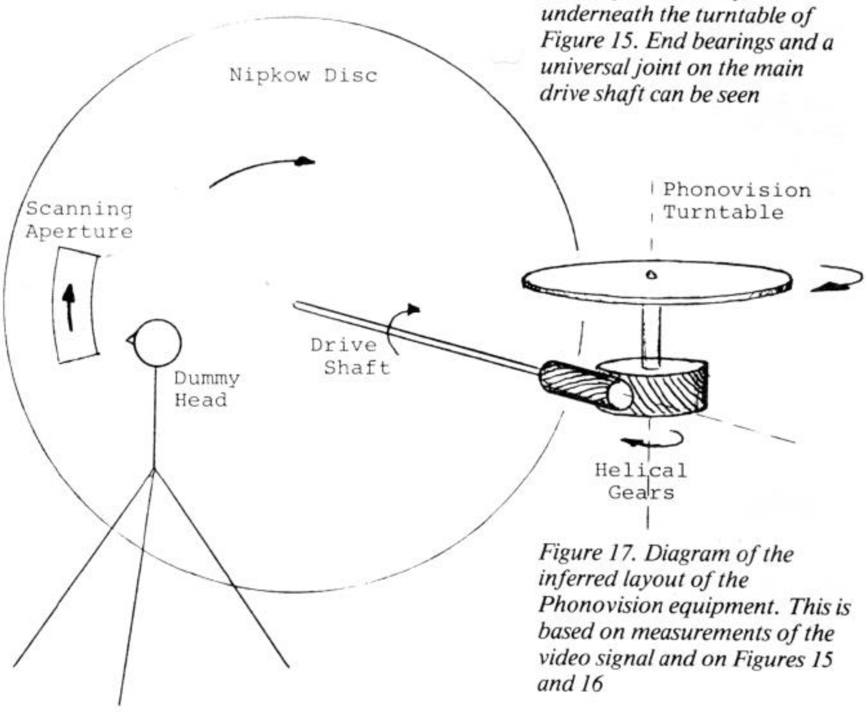


Figure 17. Diagram of the inferred layout of the Phonovision equipment. This is based on measurements of the video signal and on Figures 15 and 16

rotation of the turntable through the gearing on the photographs, the drive shaft rotates clockwise as it enters the wall in **Figure 15.** Using the fact that line 1 is the innermost of the lines and assuming no further gearing of the drive shaft, the most likely position for scanning a subject can be deduced. Shown on **Figure 17,** the position is similar to that of the dummy head on the tripod in **Figure 15.**

The dummy head faces a black hole in the wall, the scanning aperture of the Baird 'camera'. This is the 'Noctovision' experimental set-up. 'Noctovision' was a Baird invention for televising subjects without using visible light. Much publicised and demonstrated at the time (references 7, 8), it was contemporary with Phonovision.

Because of the proximity to the Phonovision apparatus and the deductions above, it would appear that the scanning disc for the Noctovision experiment was also used for Phonovision. Assuming that the drive shaft passes through the centre of the scanning disc then the disc has to be at least 1.5m (5 feet) in diameter.

Conclusions

Extracts from the 30-line television recordings of the late 1920s have been captured, analysed and processed for display through extensive use of a special-purpose microcomputer system. In their original form the recordings suffer from considerable distortion. Partial removal of the distortion has enabled recognisable moving pictures to be seen whereas its analysis has allowed details of the original experimental apparatus to be deduced. It has not been possible to restore these pictures to the original studio quality. Hence any assessment of the 30-line system based on the images shown here would be unwise.

Full credit must be given to Baird for the world's first ever electrical video recordings. The quality is so bad however that these recordings were probably never seen in the clarity we see them today. This was the most likely reason that no demonstration of pictures from the discs took place. Never intended for public appraisal, these discs are simply a record of problems encountered during development. The fact that Baird did not manage to give any visual demonstration indicates that the problems were never overcome.

The last word must go to Baird, however, who said:—

'. . . I had a gramophone record made of . . . (the vision signal) and I found that . . . I could reproduce the original scene. A number of such records were made . . . but the quality was so poor that there seemed no hope of competing with the cinematograph.' (reference 3) ■

Figure 18. Single frames taken from the January (below) and March (above) 1928 recordings

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